PALEONTOLOGY

COLLECTED PAPERS

OF

HAROLD W. FAIRBANKS

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By HAROLD W. FAIRBANKS.

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By HAROLD W. FAIRBANKS.

[Written for the Twelfth Report of the State Mineralogist, 1894.]

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1894.

GEOLOGY OF NORTHERN VENTURA, SANTA BARBARA, SAN LUIS OBISPO, MONTEREY, AND SAN BENITO COUNTIES.

By Harold W. Fairbanks.

The field work for 1893 in the southern coast ranges occupied five months. The writer, in company with R. P. Heagan, as assistant, traveled over 2,000 miles, visiting every known mineral deposit of any value, and examining the geology as far as was possible with the time at disposal. The geology was found to be more complex than the hasty reconnoissance the previous summer had indicated. Many interesting facts were discovered, for the full elucidation of which more detailed work is required. It is believed, however, that the work has been sufficiently accurate to serve as a basis for future detailed investigations.

Very little has been known of the geology of this portion of the coast ranges. The reports of the Pacific Railroad Survey, and of the former State Geological Survey under Professor Whitney, comprise the results of most of the work done here. The southern portion of the region studied, embracing as it does the San Emedio range, where the San Bernardino Sierra and the southern Sierra Nevada unite, is of great geological interest. The three dominating peaks of the San Emedio range are the Alamo, Frazer, and Pinos, ranging in the order named from over 7,000 to 9,000 ft. in elevation. This elevated region of crystalline rocks has a shape somewhat like a V, the apex formed by Mount Pinos lying to the west, while the arms extend one to the northeast, forming the Tehachapi range, the other southeast under the name of the Sierra Libre. Between these ranges is Antelope Valley, the western arm of the Mojave Desert.

Previous to the deposit of the Miocene-Tertiary this region had assumed topographical features somewhat similar to those of the present day, but during the Miocene a great submergence took place and only the tops of the highest ranges rose above the water. The Tertiary beds, consisting of sands and clays, were deposited in the previously eroded valleys, and to-day somewhat mask the real geological structure. The Miocene which forms a large part of the central and southern parts of Ventura County, extends up Soledad Cañon nearly to the Mojave Desert, while beds of the same age in the valley of the Piru completely cut off the Sierra Libre from the San Emedio range and extend through to Antelope Valley. The beds rise to an altitude of over 5,000 ft. about the sides of Frazer Mountain, where they are quite undisturbed and present a somewhat terrace-like appearance. The surface in places has apparently undergone scarcely any erosion since the elevation from beneath the sea.

The Sierra Libre range consists chiefly of a gneissoid mass with some granite, and is generally deeply decomposed. The gneiss is thin-bedded,

and in the San Francisquito Pass exhibits the most contorted foliation, while it is intersected in all directions by irregular quartz veins.

Tertiary beds extend up to the summit west of Gorman Station, where the old Los Angeles stage road crosses, and rise much higher against the slopes of Frazer Mountain. Tertiary beds appear again about the sides of Cuddy's Valley, between Mount Pinos and Frazer Mountain, and extend over the divide to Lockwood Valley. Westward from the latter point they become very prominently developed, forming the divide on the head of the Cuyama, and a great extent of barren mountainous country southwest and west of Mount Pinos. About Cuddy's Valley, which has an elevation of about 4,500 ft., the Tertiary rises nearly 1,500 ft. and is very distinctly terraced, three being noticeable on the north slope of Frazer Mountain. Overlying these clays unconformably are heavy deposits of bowlders and gravel, which in many places are rich in gold. These gravels border all the high peaks of crystalline rock, and are particularly extensive along the head of the Piru between Lockwood Valley and Rays Creek. The older sands and clays carry no gold, indicating a submergence of the whole range during their deposition, and a period of partial submergence during the formation of the gold-bearing gravels. The gold has undoubtedly been derived from the quartz veins in the schists near by. Beginning about 2½ miles above the mouth of Lockwood Creek on the Piru are a series of terraced gravel deposits, extending in a westerly direction to San Quelmo Cañon (about 15 miles), which are said to carry everywhere more or less gold. Desultory mining has been carried on here for many years; in fact, these are said to be the earliest worked placers in the State. These gravels seem to have belonged to an ancient stream which diverged from the course of the present Piru more toward Mount Pinos, and, judging from the bowlders, it may have headed there. South of the Piru at this point there are no gold-bearing gravels. The gold is not greatly worn and generally rather coarse. Farther down the Piru the gulches which head in the Alamo Mountain also contain gold.

Beginning on the southern side of the Piru near the mouth of the Alamo Creek, and extending in a northwest direction, is a series of very peculiar schists and gneisses with which the most important gold-bearing quartz veins are associated. These form a large part of Frazer Mountain, but are best exposed along the Piru and Lockwood creeks. They extend as far west as the southern slope of Mount Pinos. The strike is a little north of west, and dip to the north at a high angle. The schists are characterized by the development of alternate bands of feldspathic and hornblendic or micaceous material. Corroded feldspar crystals are scattered through the gneisses, being inclosed in a matrix consisting of irregular bands of gnarled, stringy masses of feldspathic material and layers of mica or hornblende. The gneissoid rocks often blend into well-characterized "eye" gneiss; that is, gneiss in which the generally large crystals of feldspar have undergone partial re-fusion, giving them a more or less elliptical form. These porphyritic gneisses are sometimes sharply differentiated from the schists, which at first sight seem to be of sedimentary origin and at other times blend into them. The porphyritic rocks sometimes appear as bunches in the dark compact schists. Several dikes of the "eye" gneiss were noted which had flesh-colored feldspar crystals 2 to 3 in. long and which were sharply defined from the inclosing rocks, while others which were very similar

in character, but not so coarse, seemed to blend by transitions through types in which the feldspar was more corroded to those in which it appeared as stringy masses, and finally into a typical hornblende schist. The bunchy feldspathic aggregates blending into bands undoubtedly represent crystals which had become softened by partial re-fusion and then been drawn out in the moving magma. This character is very finely shown on the Piru in the vicinity of the Castac Mine. It would seem probable that the greater portion of these hornblende and mica schists formed originally a portion of an eruptive mass.

The most easterly mine in this belt is the Castac, on the south bank of the Piru. The vein is inclosed in the crystalline schists and has a northwest and southeast course. Numerous small quartz veins occur in the schists on the southern slope of Frazer Mountain. The veins are either in a fine-grained variety of the "eye" gneiss, as, for example, the Frazer, or on the contact of coarse dikes of a flesh-colored variety with narrow bands of schists, as on the southwestern slope of the mountain, where are situated the Bunker Hill, Fairview, and White Mule mines. The mineral deposits of the San Emedio Cañon have an entirely different character.

The region about Frazer Mountain is remarkable for the number and variety of the volcanic rocks. A banded liparite appears on the northern slope of the Sierra Libre range. At Gorman Station is an outcrop of a dark basaltic rock. Near the Frazer Mine is a dike of fine-grained liparite, while on the northern slope of the mountain are coarse liparites with more basic amygdaloidal varieties. On the southern slope of Mount Pinos are extensive areas of a variety of lavas, mostly basic. The San Emedio range has been the scene of great strain and faulting along an east and west line, not only in Tertiary times, as indicated by the volcanic rocks, but also quite recently. The effects produced by a great earthquake, probably that of 1872, can be traced a number of miles along the stage road from Gorman Station to Antelope Valley, where large depressions still exist. The fissure extended west across the San Emedio Cañon for an unknown distance. Abundant springs gush out along this fault line; in fact, it can be traced by them.

Limestone in a highly crystalline condition outcrops in the granite near Gorman Station. Numerous but detached areas appear in a westerly direction from this point, being especially prominent in the range north of Cuddy's Valley, and in the San Emedio Cañon. Near Gorman Station, as well as in a branch of San Emedio Cañon, iron ores occur in conjunction with the limestone.

The northern portion of Mount Pinos consists of mica and hornblende schists, dipping at a high angle to the south. Granite, however, appears some distance down the San Emedio Cañon where it rises in peaks 6,000 ft. high. The San Emedio antimony mines are located on a high granite mountain on the east side of the cañon. A short distance below the old works the crystalline rocks are succeeded by the Chico-Tejon series, which consists to a great extent of sandstone, rising in cliffs nearly 1,000 ft. high, and exposing the stratification very clearly.

A ridge of crystalline rocks extends northwestward from Mount Pinos for a number of miles, when it sinks beneath the Tertiary, thus terminating the exposed portion of the crystalline axis, which, without doubt, continues still farther underneath the clays and sandstones to connect with the San Luis range of granitic rocks. The Cuyama River for nearly

a hundred miles down from its source may be said in a general way to divide the Miocene from the Chico-Tejon; the Tertiary extending northwest from the San Emedio region, to form the parallel ranges bounding the Carisa Plain, while the high ranges in the northern part of Ventura County about the head of the Sespe and San Buenaventura rivers, extending into central Santa Barbara County, consist chiefly of the Chico-Tejon, with occasional patches of overlying Miocene. About the very head of the Cuyama River, north and northeast of Ozena Post Office, the Miocene clays and sandstones are impregnated to a remarkable degree with alkalies, the dry bed of the streams being almost perfectly white in many places. The upper Sespe flows from west to east between high ranges of unaltered rock, which, judging from the few fossil remains found, belong to the Tejon. The highest portion of the range on the north, separating the Sespe from the Cuyama, is called Pine Mountain, having an elevation of about 6,000 ft. The shales and sandstone of this range lie quite flat, dipping slightly to the north. They form the southern half of a synclinal fold, which is very clearly shown in the region about the head of Santa Barbara Cañon. The strike is nearly east and west. A few poorly preserved fossils were collected on the northern slope of Pine Mountain. The following species were made out: *Actæonella oviformis*, Gabb; *Dentalium pusillum*, Gabb; *Fusus remondi*, Gabb; *Turritella* sp.; *Neverita globosa*, Gabb; *Meretrix horni*, Gabb. This fauna is thus seen to indicate the Tejon. Stratigraphically these beds are from the upper portion of the synclinal fold before mentioned.

Pine Mountain has on its southern slope a strip of Tertiary sandstones and clays which are exposed in bold cliffs facing the Sespe. They dip to the northeast at a small angle, and near the point where the Matillija trail crosses rise fully 1,000 ft. above the valley. They are characterized by an abundance of Miocene fossils. Although no actual contact was observed here with the underlying Tejon, everything points to a non-conformity.

The range south of the Sespe rises nearly as high as that on the north, and consists of gray sandstone, generally thin-bedded, and black shale; the strike is a little north of west, and dip either south or north at a high angle. Descending the south side of the range, the Matillija Cañon was followed down to the hot springs, where it opens out to the Santa Ana Valley. The few fossils found indicated the Tejon, and were determined as follows: *Fusus martinez*, Gabb; *Meretrix horni*, Gabb; *Crassitella grandis*, Gabb; *Dentalium cooperi*, Gabb. The shales and sandstone are uniform in character to the mouth of the cañon, but the dip and strike are very irregular, and show a great amount of crushing. The rocks are very clearly exposed in the sides of the cañon, the cliffs being in places fully 1,500 ft. high. The whole width of the Chico-Tejon exposed in this section must be as much as 12 miles, but so irregular is the dip that no estimate of the thickness can be given. The Santa Ana Valley seems to form the southern boundary of this series. From this point the Miocene extends south and west to the coast. This region is remarkable for the entire absence of eruptives of any kind. Although lavas were reported by the Pacific Railroad Survey, no traces of any were seen during the present investigation.

In a westerly direction, that is, in the eastern part of Santa Barbara County, these ranges unite to form an elevated and very rugged region

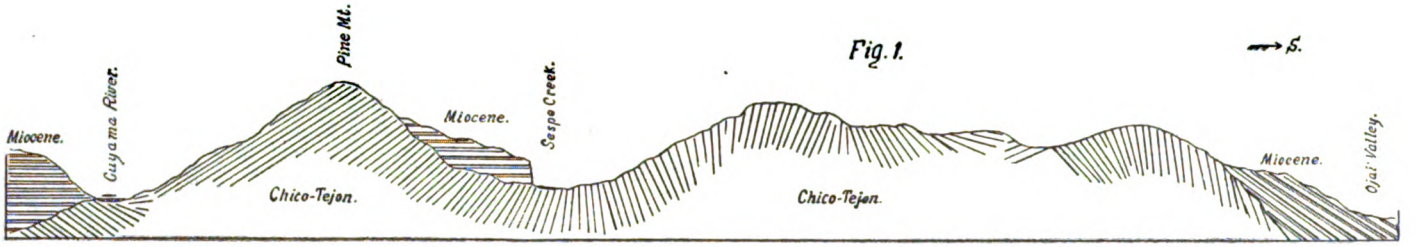


Fig. 1.
S.
Miocene.
Cuyama River.
Pine Mt.
Chico-Tejon.
Miocene.
Sespe Creek.
Chico-Tejon.
Miocene.
Ojai Valley.

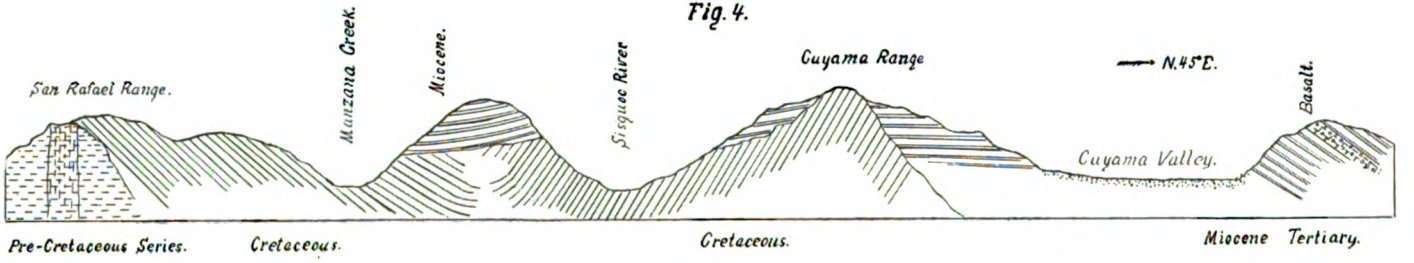


Fig. 4.
San Rafael Range.
Manzana Creek.
Miocene.
Sisquoc River
Cuyama Range
N. 45° E.
Basalt.
Cuyama Valley.
Pre-Cretaceous Series.
Cretaceous.
Cretaceous.
Miocene Tertiary.

of which very little is known. As far as our observations were carried it seemed to consist of the Chico-Tejon, overlaid in places by the Miocene. Streams flow from this watershed to every point of the compass, giving rise to the Sespe, the Sisquoc, the Santa Ynez, and important tributaries of the Cuyama. The three important ranges of Santa Barbara County may also be said to start here. These are the Cuyama, the San Rafael, and the Santa Ynez. The Santa Ynez is formed, as far as is known, of Miocene rocks exclusively; the other two of pre-Cretaceous, Cretaceous, and Tertiary. The highest peak to be found in Santa Barbara County rises about 7,000 ft., forming a sort of semi-circle about the head of the Sisquoc.

Santa Barbara Cañon, which opens north to the Cuyama River, shows a good cross-section of that portion of the mountains. Tertiary rocks appear for about 5 miles up the cañon. The beds consist, at the base, of the usual clays, richly impregnated with gypsum. Higher up there is red sandstone, dipping but slightly to the north, that is followed by soft, heavy-bedded sandstone of a light-yellow color. The latter are inclined at a steep angle and rest on the Chico-Tejon, which consists of dark shale and thin-bedded sandstone, dipping about 70° to the southwest. In appearance these rocks are very similar to those on the Matillija. From this point to the head of the cañon, a distance of about 8 miles, the Chico-Tejon continues, dipping 60° to 80° to the southwest, and strike N. 60° to 70° W. As the divide is approached the sandstones assume a tawny-yellow color, and contain dark concretions similar to those elsewhere in this series. Although no fossils were found in the cañon, the strata appear to be the direct continuation and to belong to the same series as those crossed on the Matillija trail. On the summit opposite the head of Meno Cañon a reversion of the dip takes place, and the high mounains on the head of the Sisquoc and along the upper Mono Cañon repeat, only in opposite order, the strata passed over in Santa Barbara Cañon. The thickness of this series as shown in the latter cañon is enormous. The dip is quite uniform, and unless the strata are repeated by faulting, of which no traces were observed, it must be 25,000 ft. *Fig. 2* is a section in this cañon.

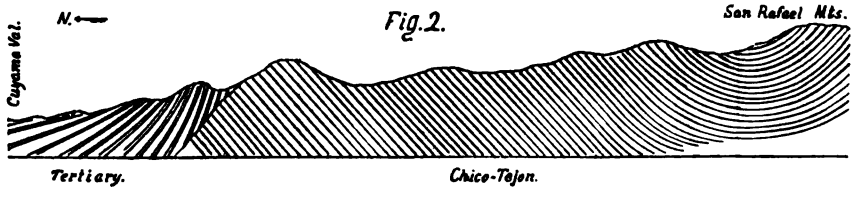


Fig. 2.

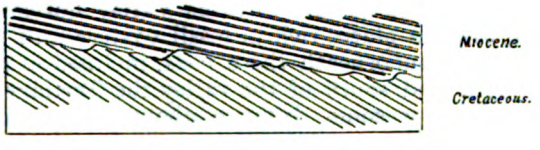
The Cuyama range was crossed about 15 miles west of Santa Barbara Cañon, opposite the Cuyama ranch house. At the point where the trail crosses there is a depression in the Chico-Tejon, and the light-yellow sandstones so characteristic of the Miocene in this section extend from the eastern side over the summit a short distance. The older gray sandstones and shales appear in the higher portions of the range both north and south. The Miocene sandstones are heavy-bedded, and seem to dip away from the axis of the range at a small angle. The sandstone weathers out in great knobs, and in a cañon north of Montgomery's Potrero forms a very extensive series of high-terraced cliffs, known as

the Painted Rocks. Five terraces appear, each fully 100 ft. high. The rocks exposed in the cañon of the Sisquoc for many miles belong to the Chico, judging from a number of specimens obtained from the cañon a little above the point where the Jackson trail strikes it. The following forms were determined: *Inoceramus; Baculites chicoensis*, Trask; *Dentalium stamineum*, Gabb; *Cinulia obliqua*, Gabb; *Pectunculus veatchi*, Gabb; *Meekia sella*, Gabb; *Clychna costata*, Gabb; *Tellina ashburneri*, Gabb.

While dark sandstone and shale form the prevailing rocks, yet there are very extensive beds of bowlder conglomerate. The bowlders are chiefly of the granite type, and sometimes are as much as 3 ft. in diameter. A southerly dip predominates, though that, as well as the strike, is very irregular.

A range of rugged mountains lies south of the Sisquoc between it and the Manzana. The higher portions of these mountains are capped by Miocene sandstones, but slightly disturbed and contrasting strongly with the underlying Cretaceous. As the cañon is ascended, the Cretaceous gradually sinks and the light-yellow sandstones appear in bold bluffs along the water's edge near where the stream divides. The Tertiary overlies the Cretaceous unconformably, a fact which was illustrated by an excellent exposure on the Sisquoc, where the older shales and sandstone dip south about 30° and are overlaid by the Tertiary sandstone, which rests on their irregularly eroded surface with a considerably smaller dip. Iron springs are numerous along the contact. *Fig. 3* illustrates the non-conformity.

Fig. 3.



The three ranges, the Cuyama, the San Rafael, and the intervening one, have each an elevation of about 4,000 ft. along a section between the town of Santa Ynez and the Cuyama ranch house. The geology of this section is illustrated by *Fig. 4*.

The Cuyama Valley has a length of 35 miles, gradually narrowing toward the western end, where the river turns to the southwest and cuts across the Cuyama range. On the north of the valley, and separating it from the Carisa Plain, is a range of high and barren Tertiary hills formed of gypsum-bearing clays and soft sandstones. These rise quite abruptly from the valley, exposing well their stratification. The hills were explored for a dike which was reported to carry silver, and as a result the occurrence of a most interesting eruptive mass was brought to light. An immense dike of the diabase type and rich in analcite was found to extend for several miles in a northerly course on the western slope. At the southern end the width is at least 1,500 ft., narrowing somewhat to the north. The great mass of the rock is so completely decomposed as to give the same contour to the hills as the soft Tertiary beds, and if it were not for the presence of many small but harder dikes traversing it, and for the rather precipitous croppings in the narrow

cañons, its presence would hardly be suspected. The substance from which the analcite has been derived is not certainly known, but it is probably nepheline, or some related mineral. The susceptibility to decay and the disintegrated condition of the whole mass must be due to some mineral of this class. Dikes of somewhat different composition and structure cut through the decomposed portion in every direction. They vary in width from a few inches to nearly 20 ft., and are quite hard and fresh. The analcite is present in some of these dikes in clear glassy grains fully half an inch in diameter. In places they are undergoing decomposition to radial zeolites. The other components of the rock are feldspar (plagioclase), augite, and ilmenite (titanic iron).

The Tertiary has been thrown into a vertical position adjoining the dike and very considerably metamorphosed. This metamorphism consists of a hardening of the clays and their transformation to dark shales, while the sandstone and calcareous strata have been partially recrystallized. A great mass of Tertiary shales has been inclosed in the eruptive mass, as shown in the side of one of the cañons. Excellent specimens, showing large cleavable crystals of diallage and grains of analcite, were obtained from one of the dikes about 15 ft. wide. The large dikes are, as a rule, coarse, but show little difference as regards this character between the centers and the edges.

On the summit of this range, between the Cuyama ranch house and the Carisa Plain, is a series of volcanic beds, probably basalt, interstratified with the Tertiary clays. They vary in thickness from 10 to 100 ft., and extend along the crest for several miles. Judging from the float, another outcrop is to be found in the same line of hills opposite the lower end of the Cuyama Valley.

Toward the lower end of the Cuyama Valley horizontally bedded Miocene hills appear, in places rich in fossil oysters and pectens. The Chico outcrops from underneath these beds, inclined at a considerable angle. Both north and south of the valley the Tertiary itself is considerably inclined. For some distance above the main cañon, and north of the point where it turns to enter the mountains, there are very extensive conglomerates, probably nearly 2,000 ft. in thickness. They form high mountains in the southern part of San Luis Obispo County, being really a continuation of the Cuyama range, only under another name. Continuing in a northwesterly direction, this range becomes still higher until divided by the San Luis Valley, at the upper end of which the Salinas River rises. The northern arm unites with and overlies the southern portion of the San Luis range of granitic rocks. The southern arm forms the watershed between the Salinas and the Alamo, the Arroyo Grande, and the Corral de Piedra creeks, which empty directly into the ocean. In its northwest prolongation this range forms the Santa Lucia.

The Cuyama River turns to the southwest several miles below where it enters the cañon, and for a distance of 20 miles cuts through the mountains at right angles to the strike of the rocks, giving an excellent section of all the formations represented in Santa Barbara County except the Pliocene. For several miles before turning to the southwest the river is bordered by heavy-bedded conglomerates, dipping southwest at about 30°. At the very point where the course changes, shales and dark sandstones appear underlying and nearly level. There is an appearance of non-conformity, but both series probably belong to the Cretaceous. The presence of pebbles similar to the underlying sandstone in

the conglomerate near its base, and their absence at a greater distance, favor this view. The shales and sandstone present a very regular bedding as exposed down the cañon. They finally become nearly vertical, then for some distance present a dip of 30° to 40° to the north, and are last seen resting against an older and greatly altered crystalline rock. Higher up on the sides of the cañon they rest on this ancient eruptive.

A mile back from the main cañon, on the south side and about 700 ft. above, is a remnant of the Miocene overlying the Cretaceous. The strata dip at a gentle angle to the northeast, and consist of light-colored, chalky, or calcareous rocks above, containing scattered and imperfect pectens, and at the bottom soft clays. There can be no doubt that these beds are unconformable on the Cretaceous, though no actual contact was observed.

The series underlying the Cretaceous appears for about 5 miles along the cañon, and consists of rocks of a greatly varied character. The first of the older, or pre-Cretaceous series, is a dark-green eruptive, seamed with epidote and so changed that the individual constituents cannot be made out with the unaided eye. This eruptive is succeeded down the cañon by other dark, fine-grained rocks, also evidently eruptive in origin. Below the eruptives on the rugged walls of the cañon are shown hard sandstones containing quartz veins, jasper, and serpentine. The last exposure consists of greatly contorted and crushed shales and sandstones filled with a network of minute quartz veins. The contact with the Cretaceous on the western border of the older rocks was not observed, but it appears a short distance away and continues for 2 miles down the cañon. The rocks of the latter formation consist of dark shales and gray sandstone dipping southwest at varying angles. They show no crushing or quartz-veining. The rest of the cañon to its mouth where it debouches on the Santa Maria Plain, is bordered by mountains of Miocene rocks, much disturbed and inclined at high angles. The contact with the Cretaceous was not plain, but it seems to be indicated by a conglomerate wholly unconsolidated, and which is followed a short distance down the cañon by the usual soft clays and sandstones of the Miocene. The conglomerate overlies the Cretaceous unconformably, has a distinctly reddish tint, and consists of angular sandstone fragments and well-worn pebbles. *Fig. 5* is a section along the road from Santa Maria to the Cuyama Valley, following the cañon most of the distance.

The geology of the region about the head of the Santa Ynez River is very complex, and though many new and interesting facts were noted, yet time did not permit of detailed work sufficient to illustrate the structure clearly or the relation of the various formations to each other. It was found, however, that there were extensive areas of the Tejon, the Miocene, and smaller ones of the Lower Cretaceous. There can be no doubt that the main portion of the Santa Ynez range is Miocene, with a general anticlinal structure, well known in the San Marcos Pass. The center of the anticlinal is not generally the highest portion of the range, but lies on the eastern slope. The normal type of anticlinal structure is also masked by an east and west compression, producing features, however, of secondary importance. As viewed from the south at various points the range consists of heavy-bedded sandstone, dipping at a high angle to the south. The foothills and plain bordering the ocean, consisting of a higher portion of the same series, are mostly soft shales and clays,

Fig. 5.

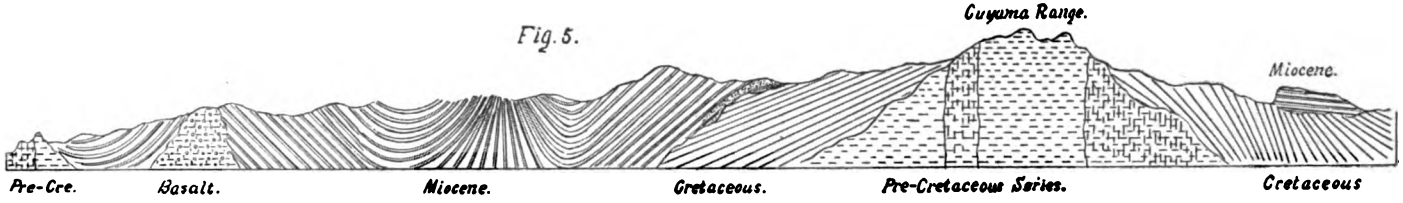
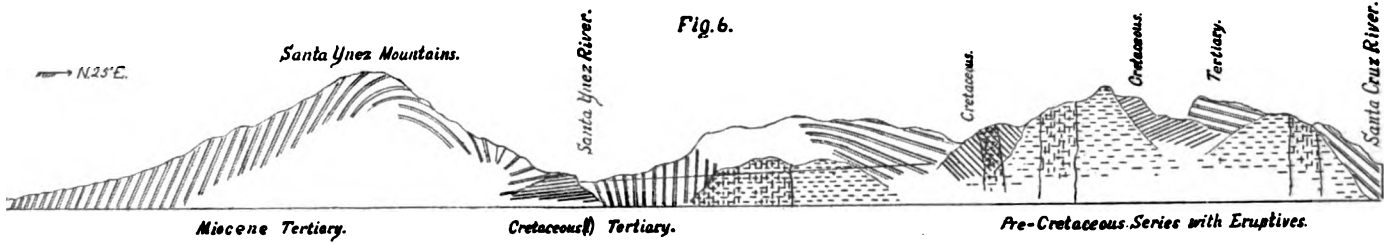


Fig. 6.



gradually becoming more flat as the ocean is approached. At the western end, in the vicinity of Point Arguello, no anticlinal structure is apparent, but steeply inclined and broken strata. Asphaltum is found in many places near the sea from Point Arguello to Ventura County. Antisell, in the report of the Pacific Railroad Survey, reported trachytic axes from many points in this range, but examination made it evident that he mistook areas in which the oil or asphaltum had been burned for eruptive bodies. There are numerous such areas in the vicinity of asphaltum deposits where the rock has been baked and partly fused.

The Santa Ynez River in its upper course runs close to the northern base of the Santa Ynez Mountains. On the north of the river rise quite abruptly the foothills of the San Rafael range. There is thus formed a rugged and narrow cañon where the formations are well shown. Several large cañons which come in from the north also give excellent opportunities for study. Beginning in Oso Cañon and extending in a slightly northwest direction for about 25 miles is an almost buried ridge of the pre-Cretaceous series. Nearly all the main tributary cañons of the Santa Ynez on the north cut across this ridge, which at its western end extends nearly to the summit of the San Rafael Mountains. As in the cañon of the Cuyama, this series consists of argillaceous rocks and sandstone greatly crushed, stratification being often nearly or quite obliterated, while silicification is more or less pronounced. Red jasper is the most striking rock present, and covers a considerable area. Serpentine, dark, fine-grained intrusives, and glaucophane schist also appear. On the sides of the older area are beds of black shale in which several intrusions of serpentine appear. Everything points to the fact that the serpentines all date from a time prior to that represented by the Chico. If this is a fact, then all rocks intruded by it must be at least as old as the Lower Cretaceous. Fossils indicating the Chico, or possibly the Lower Tejon, were found in strata apparently overlying those intruded by serpentine. The Miocene is very extensively developed. It consists of the bituminous slate series and sandstone, in some places but slightly disturbed, in others folded in with the Cretaceous. A great amount of faulting has taken place on both sides of this pre-Cretaceous axis, rendering the structural relations exceedingly difficult of elucidation. The notes here given make no pretense of accuracy in detail, but are intended to indicate what may be looked for. The scarcity of fossils in all the formations adds greatly to the difficulty.

The serpentine appears in places for 10 miles to the east of the last outcrop of the pre-Cretaceous axis. It is inclosed in black shale and limestone. In two spots it has been metamorphosed by mineral solutions with the deposit of cinnabar. Many years ago each of these localities was worked for that metal. At the lower mine, the Los Prietos, the river has cut through great cliffs of red gossan, which is inclosed in unaltered serpentine. In contact with the serpentine on the south is limestone; on the north, shale. The dip of both walls is nearly vertical at the contact. The appearances indicate that the north wall has been bent down toward the vein, while the south has been bent up. A half mile above, the shale, with thin beds of sandstone, appears in nearly vertical cliffs fully 1,000 ft. high, facing the river. In this great cliff, as well as for several miles up the river, whose general course follows the serpentine, the strata are crushed and broken. Several fossils were obtained from these rocks. They were determined as follows: *Cardium*

breweri (?), Gabb; *Olivella mathewsoni* (?), Gabb; *Scalaria mathewsoni* (?), Gabb.

Four miles up the river is the Santa Cruz Mine, where the serpentine, inclosed in black shale, outcrops nearly 600 ft. above the bottom of the valley. In Mono Cañon, a tributary from the north, a little to the east of the mine there is no appearance of the Chico-Tejon. The rocks for a number of miles consist of the bituminous slate series of the Miocene. Between the two mines the river has eroded a channel across the strike of a body of Miocene sandstone exposing a perfect anticlinal arch. Terraces of bowlders and gravel appear nearly 500 ft. above the river at the Santa Cruz Mine.

A little above the point where the stage road over the San Marcos Pass strikes the river is another small outcrop of shales, supposed to be Cretaceous.

Fig. 6 is a section across the Santa Ynez range and through Red Rock Cañon. It is given particularly to illustrate the complicated structure shown in the latter cañon. In the lower portion of the cañon there are exposed three series of rocks: The pre-Cretaceous at the bottom, consisting of glaucophane schist and other altered eruptives, sandstone, and shale; resting on these are flinty beds of unknown age, and apparently unconformable, while on the top is the Miocene, forming an anticlinal over the submerged ridge of older rocks. These older rocks are well shown at the head of the cañon, where there is an immense outcrop of banded jasper, known as the Red Rock, rising vertically 300 ft. In direction of strike the jasper crops prominently to the east in Oso Cañon and to the west in many places for a number of miles. The older series contains in addition to jasper, sandstone, shale, glaucophane schist, serpentine, and other decomposed eruptives.

On both sides of the ridge between Red Rock Cañon and the Santa Cruz River are small exposures of black shale and thin-bedded sandstone, not greatly crushed, and very closely resembling the Lower Cretaceous, as it is generally known through the State. These rocks dip toward the center of the hill, which consists of the pre-Cretaceous. On the south the shales are exposed in a high cliff, and are full of nodular calcareous concretions. A dike of serpentine has been intruded into these shales conformably to the strike and dip. This is beautifully shown on the face of the cliff. Although no fossils were found, it seems highly probable that these unaltered strata belong to the Lower Cretaceous. The hills at the head of the cañon are capped by a Tertiary sandstone dipping north at a small angle. From the divide the deep cañon of the Santa Cruz is seen to head in very rugged mountains nearly 7,000 ft. high. Rocks apparently of Cretaceous age outcrop also in Oso Cañon. They dip nearly vertical, and are overlaid at the head of the cañon by a great thickness of Tertiary strata.

The Cretaceous and older rocks are again well exposed in Cachuma Cañon, which heads in the San Rafael Mountains north of the town of Santa Yñez. On the south the Tertiary clays dip into the range resting on the pre-Cretaceous series, which consists of jasper, sandstone, and shale with dikes of serpentine. The cañon cuts through this ridge of older rocks, then turns to the northwest, having eroded its channel along the contact between the Cretaceous and the basement rocks. The Cretaceous consists of black shales with some beds of sandstone, resting nearly vertically either against the basement rocks or the serpentine,

which has been intruded on the contact. Toward the head of the cañon the shales are filled with calcareous nodules resembling those in Red Rock Cañon. These rocks form the lowest part of the Cretaceous at this point, and may represent the Knoxville, as there is not much doubt about the intrusion of the serpentine into them. One of the tributaries of the Manzana heads opposite the head of Cachuma Cañon and flows northeasterly nearly at right angles to the strike. Following down this stream shales and sandstone are the only rocks to be seen for 3 miles. The dip is less than at the base of the series, being 50° to 60° northeast. About 2 miles down the cañon an ammonite was found, but in too bad a state of preservation to indicate anything more than the Cretaceous. These beds extend about half way from the divide to the Manzana, where they are replaced by vast beds of conglomerate formed of very smoothly rounded pebbles. The conglomerate has interbedded with it thin strata of shale and sandstone, and is undoubtedly a part of the Cretaceous. However, it dips considerably less than the underlying shales, but the exposures were not good enough to decide with certainty if an unconformity existed. The shales and sandstones have a thickness of as much as 8,000 ft., and the conglomerate several thousand more. The latter outcrop along the Manzana, and form the basal portions of the high mountains between it and the Sisquoc, the upper portions of which are formed of Miocene sandstone. In the upper part of Brown's Cañon, which heads several miles to the north of the Cachuma and empties into the Manzana, there are quite extensive dikes of basalt and serpentine intruded in the Cretaceous. The basalt is quite fresh and presents a variety of characters. It is present solely in the form of great dikes, and is said to extend several miles to the northwest. The crystalline rocks along this part of the San Rafael range are varied and of considerable interest.

The western half of Santa Barbara County, with the exception of a few small areas, is formed of middle or late Tertiary; the ranges of mountains between the parallel valleys which open to the northwest being Miocene, while the Pliocene is probably represented along the low hills bordering the level Quaternary valleys. The presence of large bodies of asphaltum and bituminous rock is very characteristic of the Miocene over much of this area.

The Santa Ynez Valley narrows about 10 miles below the old mission, and the river flows between Miocene hills until the Lompoc Valley is reached. On the south side of the river, where it leaves the Santa Ynez Valley, is a high, precipitous outcrop of volcanic tufa, and in the Miocene beds resting upon it are bowlders of a black basalt. Opposite Buell's ranch a cañon comes in from the Santa Ynez Mountains. In this cañon shales and sandstone of undoubted Cretaceous age show a width of more than a mile. They form an east and west line of hills bordering the Santa Ynez River for several miles. The shale alternates with thin layers of a dark sandstone and nodular calcareous strata similar to those seen in the supposed Lower Cretaceous in other portions of the county. The strata have undergone considerable crushing, and are in various positions; generally, however, they are quite flat, and toward the south have a southerly dip. A mile and a half up the cañon they are replaced by tawny, heavy-bedded sandstone, often showing no stratification. This sandstone forms all the higher country toward the Santa Ynez Mountains, and dips gently to the south and southwest. It contains poorly preserved specimens of *Pectens* and *Ostreas*. In a side

cañon which comes in from the west there is an excellent section showing the contact between the buff-colored sandstone and the dark shales. Both formations dip to the west, the sandstone 20° and the shale 37°. The non-conformity is very evident. The Cretaceous shales appear in only a few places along the road from the old mission to Gaviota, being almost completely covered by the Miocene. Heavy beds of bowlders of a serpentinous gabbro cap the hills west of the road about 3 miles south of the river. The large bowlders of coarsely crystalline gabbro, generally not much worn, are imbedded in a matrix of sand and small sandstone pebbles. It is not certain whether this is an old beach line or river bed. Associated with the large bowlders are small ones of jasper.

The Santa Ynez range at this point has a bold northern escarpment, rising over 1,500 ft. very abruptly. At the crossing of the river near the mission the sandstone dips northerly, while the high portion of the range dips to the south. There is here a rude anticlinal with an axis of Cretaceous rocks. The axis was not traced up the river on the south side, but it is probable that it appears in several places.

A short distance north of Lompoc Landing a reef of gabbro and serpentine extends out into the ocean for several miles.

Point Sal shows a bold face to the south and west. It consists of serpentine and other basic rocks. These extend for several miles, and are capped by Miocene clays and sandstone. The latter dip away from the crystalline axis, and are finely shown in the vicinity of the gypsum mines. Serpentine proper forms only a part of the crystalline rock, but is mixed in the most confused manner with gabbro and pyroxenic rocks, coarse to fine-grained, and quite variable as regards the relative abundance of the different components. Much of the serpentine is very fine-grained, and has inclosed bunches of all shapes and sizes of gabbro, and is, in addition, cut by dikes of the same. At times the boundaries between the two are sharp, at others there is a blending.

Dark, fine-grained eruptives outcrop through the Miocene on the summit of the ridge where the road to Santa Maria crosses it.

Another outcrop of the pre-Cretaceous series is to be seen on the Suey grant, north of the Santa Maria River. The formation seems to be the continuation of the ridge of rocks of the same age in the central part of Santa Barbara County. It consists of glaucophane schists and hard sandstone, and contains dikes of serpentine.

A series of ancient lavas begins on the ridge north of Fugler's Point, and extends in a northwest direction many miles, cropping on the western slope of the hills which border the Nipomo ranch on the north. Where the Cuyama road crosses this ridge the lava is a dark, fine-grained basalt. On the Nipomo ranch it has been much silicified by the action of hot springs now extinct. Agate-like chalcedonic nodules are abundant along the base of the hills for several miles. The basalt disappears 3 miles north of Nipomo, and a liparite much decomposed outcrops in places along the side of the valley nearly as far as Arroyo Grande. In places it is with difficulty distinguished from the Miocene sandstone. The line of ancient silicious springs was traced as far as Arroyo Grande. The silicification is not confined to the volcano rock, but appears also in the Miocene. The springs probably indicate an important fissure system, which may be traced northwest to Morro Bay by the numerous bodies of acid eruptives. Near Arroyo Grande the bituminous slate series has been mineralized with the deposit of iron pyrites, leading to a useless

Fig. 7.

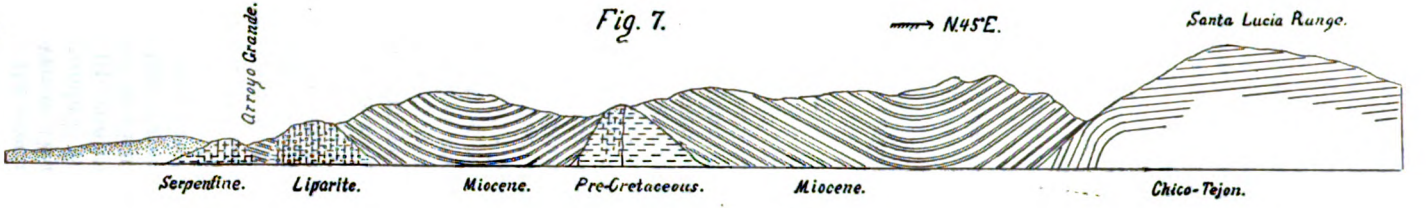
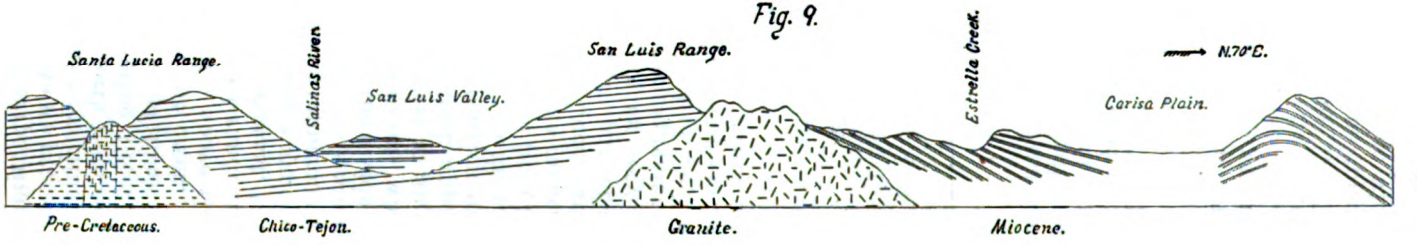

Arroyo Grande.
N.45°E.
Santa Lucia Range.
Serpentine.
Liparite.
Miocene.
Pre-Cretaceous.
Miocene.
Chico-Tejon.

Fig. 9.


Santa Lucia Range.
Salinas River.
San Luis Valley.
San Luis Range.
Estrella Creek.
N.70°E.
Carisa Plain.
Pre-Cretaceous.
Chico-Tejon.
Granite.
Miocene.

2F

search for the precious metals. A small outcrop of serpentine appears south of Arroyo Grande near Los Barros Creek. As we proceed up the Arroyo Grande it is noticed that the Miocene forms a synclinal, dipping from the liparite on the southwest and on the north from serpentine, jasper, and sandstone, which outcrop on Tar Spring Creek. Before reaching the serpentine, high cliffs of a fine-grained liparite appear rising through the Miocene on the south bank of the creek. Liparite also outcrops on the Arroyo Grande about 5 miles above the mouth of Tar Spring Creek. Still farther up the Arroyo Grande it is found that for several miles the Miocene dips to the northeast, but before reaching Music it changes to the southwest, forming a synclinal, and consists of heavy beds of granitic sandrock bearing numerous fossils of the gigantic fossil *Ostrea*. Lower in the series these beds are replaced by argillaceous rocks, and on the Wasno, just over the divide from the head of the Arroyo Grande, the Miocene terminates in soft, white sandstone with very heavy bedding, and dipping southwest at an angle of 45°. A few feet away on the opposite side of the creek appeared the Chico, consisting of coarse-yellow to gray sandstone, conglomerates, and some shale. The beds dip at an angle of about 80° to the southwest. The actual contact was not observed. *Fig.* 7 is a section from the ocean up the Arroyo Grande to the summit of the Santa Lucia range.

The Chico forms the southern portion of the Santa Lucia range as far north as the Rinconada Quicksilver Mine. The main part of the series consists of coarse sandstone and conglomerate, dipping very regularly at a small angle to the southwest. The dip becomes greater as it disappears underneath the Miocene on the Wasno. North of the Rinconada Mine it is gradually replaced by the Miocene, and continues to form only the northeastern slope of the mountains facing the Santa Margarita Valley.

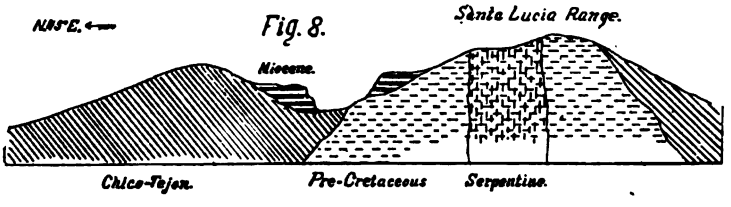


Fig. 8.

Fig. 8 shows a section of the Santa Lucia range near the Rinconada Mine. On the summit, southwest of Poso, where the trail crosses the Wasno, serpentine and the pre-Cretaceous sandstone and jasper outcrop in a long narrow exposure, with the Chico rising somewhat higher on either side. The younger series shows no disturbance. The older rocks become more prominent to the northwest, and at the Rinconada Mine are a mile wide, and consist largely of serpentine. Beyond this the older rocks become less prominent, occupying only a narrow strip through the foothills of the Santa Lucia range nearly to Santa Margarita Station. Four miles southwest of the town a deep cañon was examined, in which it appeared that the bituminous slate series (Miocene) had taken possession of the whole range, dipping 60° S.W., strike N. 40° W. The slates show the best cleavage of any seen in the Tertiary. The upper foothills are formed of heavy-bedded sandstone and black shale, in which fossiliferous limestone nodules were found. All the fossils were of one species,

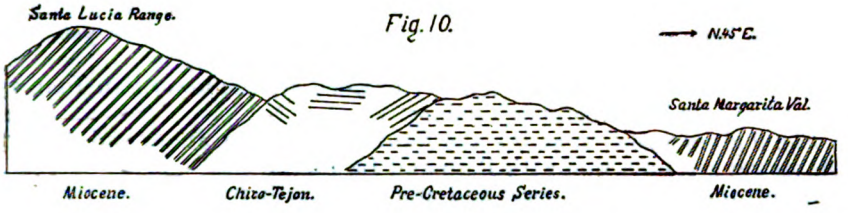


Fig. 10.

namely, *Venus lenticularis*, Gabb. This formation then belongs to the Chico. About 5 miles up the Santa Margarita Valley, on the same range, the following species were found: *Trigonia evansi*, Meek; *Axinea veatchi*, Gabb. These also indicate the Chico. *Fig. 10* shows a cross-section of the range for 4 miles south of Santa Margarita.

South of Santa Margarita the pre-Cretaceous series consists of hard-jointed sandstone and jasper. Eastward in the bottom of the valley the Miocene shales again appear, dipping at a high angle to the southwest. As the valley is crossed in the direction of the Salinas River, coarse, loosely cemented sandstones, carrying *Ostrea titan*, replace the slate, and are in turn followed by granite near the river. The stratigraphical relation of the *Ostrea*-bearing sandstone to the bituminous slates is not certainly known; it would appear, however, from the section on the Arroyo Grande that the sandstones are below.

The granite occupies a considerable area of bushy hill country north of the river, and a few miles to the southeast rises in the high San Luis range. This range is bordered on the south between Santa Margarita and Poso by hills of white Miocene sandstone. The road from Poso to La Panza passes over granite nearly the whole of the distance. The summit of the range where the road crosses has an elevation of 2,700 ft. A large part of the crystalline rocks of this range contain much glassy feldspar, and some portions are porphyritic. Dikes of a fine-grained granite with flesh-tinted feldspar are abundant, particularly on the western slope. They vary from a few inches to many feet in width, ramifying in all directions in the coarse granite. Titanite in small yellow crystals is abundant in the main body of the granite. On the eastern slope, 6 miles from La Panza, a body of limestone is inclosed in the granite. The granite crosses the range diagonally, extending in a more easterly direction. At La Panza the outcrop is much narrower, and on the San Juan Creek, 4 miles below the Carisa ranch house, it disappears. The formation replacing the granite in the southern portion of the range is a series of conglomerates and sandstone of great thickness, and dipping southwest at a low angle. These connect with the Cuyama and Santa Lucia ranges at the head of the San Luis Valley, and are undoubtedly a portion of the Chico. These beds do not extend much east of the head of the San Juan Creek, though the exact demarcation between them and the Miocene has not been traced out. The Carisa Plain is bordered wholly by rocks of Tertiary age. The Mount Diablo range on the east has an elevation of 3,300 ft. at the Temblor Pass. In the pass a sort of anticlinal structure was noted, but the mass of the range at this point seems to be a monoclinal, with dip to the northeast. As La Panza is approached from the Carisa Plain the Tertiary assumes a northeast dip away from the granite, and is characterized by *Ostrea titan* and other Miocene fossils. The La Panza placers occur near the

junction of the Chico conglomerates with the granite, but whether the god has been derived from them or from the granite has not yet been settled.

As far as is known, all the country drained by the lower San Juan is formed of middle and upper Tertiary.

Fig. 9 gives a section across the Santa Lucia, San Juan, and Mount Diablo ranges, on a line with Poso and La Panza.

Returning now to the coast and working north from Arroyo Grande, we find another outcrop of trachyte a little north of Pismo. The region about Port Harford is rather an interesting one. A line of irregular Tertiary hills extends northwest from Arroyo Grande, lying west of the valley of San Luis Obispo. These are known in their western portion as the Buchon range. For several miles northwest from Arroyo Grande the Tertiary consists of soft sandrock impregnated with asphaltum over considerable areas. As exposed along the railroad to Port Harford, the strata consist of sandstone and bituminous slates in the form of a synclinal, dipping to the southwest from the older rocks west of Los Osos, and to the northeast from Port Harford. At the latter point the Tertiary appears resting on a complex of eruptives and crushed sandstone and jasper of the pre-Cretaceous series. From the dock to Whaler's Point the eruptives are very much decomposed. In a railroad cut a little to the east there appears a dike of somewhat fresher appearance, probably a diabase porphyrite. Irregular masses of serpentine appear in places crushed to a green clay.

The older series of sandstone, jasper, and slate, and intrusions of serpentine outcrop in small exposures on the western slope of the Santa Lucia and a little north of Arroyo Grande. Widening to the northwest this series forms the underlying rocks of the valley of San Luis Obispo as far as Morro Bay. It is also prominently developed in the hills on the eastern slope of the Buchon range. Serpentine forms the main crest of the Santa Lucia range for many miles to the northwest from the point where the old stage road crosses. The hills bordering the valley of San Luis Obispo on the west, from the point where the railroad to Port Harford cuts them, for several miles northward show large areas of serpentine. Large amounts of chromic iron have been taken from this region. The pre-Cretaceous rocks outcrop in the hills for 2 or 3 miles west of the serpentine near the head of Los Osos Creek. They consist of jasper, sandstone, and shale, with some intrusives of a dark, fine-grained character. *Fig. 11* represents a cross-section from Port Harford to the Salinas River, passing near the town of San Luis Obispo.

The line of buttes extending northwest from San Luis Obispo to Morro Bay is one of the most striking features in the topography of the county. The buttes consist of trachyte, which is quite uniform in texture and composition. Two small buttes rise out of the valley southeast of the town of San Luis Obispo, but the lofty and precipitous ones all lie between the town and Morro Bay. The trachyte rests on serpentine, as well as on the pre-Cretaceous series, thus showing it to be younger. It is quite possible that the material of each butte may have had a separate source, for now, at least, they are all separated from each other by depressions almost as low as the valley itself. The rock in these depressions belongs to the pre-Cretaceous series. The altitude of the main peaks varies from 1,500 to 2,000 ft., with a thickness of liparite of perhaps 1,000 ft. For several feet from the surface the rock

Fig. 11.

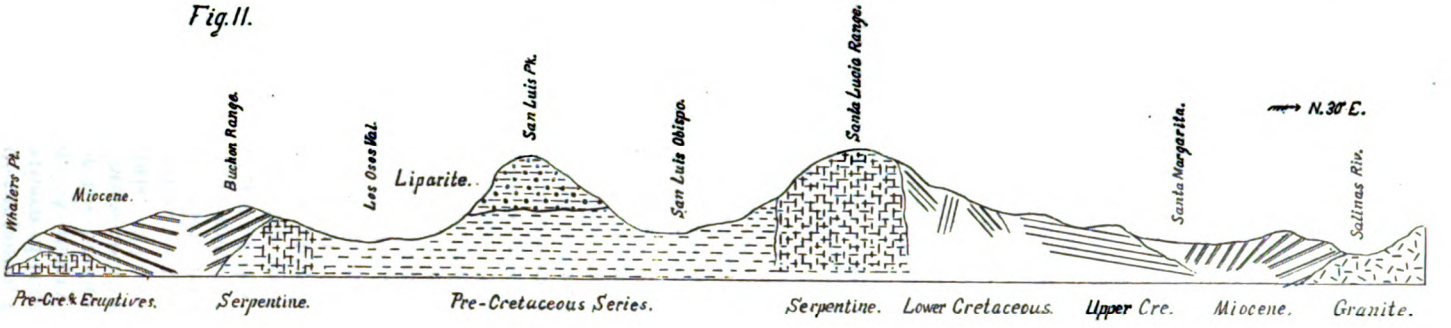
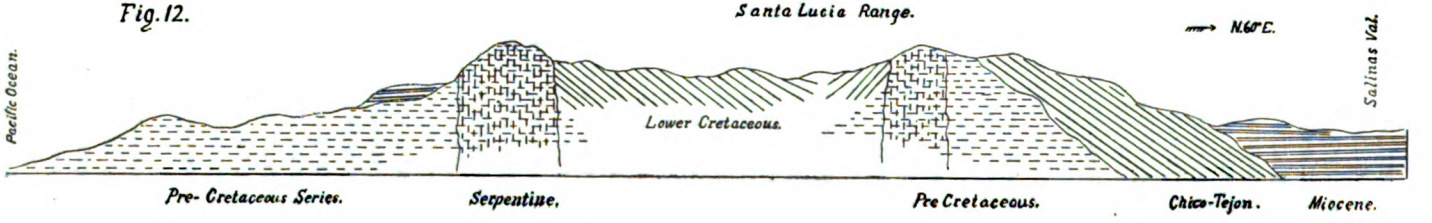

Whalers Pt.
Miocene.
Buchon Range.
Los Osos Val.
Liparite.
San Luis Pk.
San Luis Obispo.
Santa Lucia Range.
Santa Margarita.
N. 30° E.
Salinas Riv.
Pre-Cret.s Eruptives.
Serpentine.
Pre-Cretaceous Series.
Serpentine.
Lower Cretaceous.
Upper Cre.
Miocene.
Granite.

Fig. 12.


Pacific Ocean.
Santa Lucia Range.
N. 60° E.
Salinas Val.
Lower Cretaceous.
Pre- Cretaceous Series.
Serpentine.
Pre Cretaceous.
Chico-Tejon.
Miocene.

is discolored and decomposed, the original color being a gray. Morro Rock, the most northern of these buttes, is a bare mass rising about 600 ft. above the ocean. A quarry has been opened at the eastern end to supply material for the breakwater at Port Harford. Excellent specimens of fresh rock were obtained here, containing quite a sprinkling of small titanite crystals. The rock would make a good building-stone if it did not discolor on exposure.

The pass through which the road runs from San Luis Obispo to Santa Margarita divides the Santa Lucia geologically. On the southeast the Tertiary forms the crest of the range for several miles. On the northwest serpentine forms the crest and western slope. The eastern slope consists of black shale, judged to be Lower Cretaceous, because of the presence in it of a stratum rich in fossils of the genus *Aucella*. The black shale is seen first in the cañon southeast of the railroad tunnel. The tunnel cuts it for 600 ft., while the rest of the rock passed through is serpentine of varying character. The new railroad cuts have exposed some interesting tufa-like rocks of volcanic origin on the northern slope of the range. From this point down the creek to Santa Margarita the Chico sandstones outcrop. They continue to be very extensively developed on the northeastern slope of the range for many miles to the northwest. In fact, future examination showed that they were almost continuous to the head of the Arroyo Seco, in the western part of Monterey County. Five miles west of Santa Margarita the dark Cretaceous shales have a width of nearly a mile. On a trail which crosses this shale and leads up to the old Padre Mine, there is exposed a stratum at least 10 ft. thick, filled with rather poorly preserved specimens of the genus *Aucella*. The strata dip into the mountain at a small angle. The shales do not come into direct contact with the serpentine at this point, but are separated by a dike of diabase. They are considerably metamorphosed near the diabase, while a narrow stratum between the diabase and the serpentine is very much changed. The shales extend across the range on the head of the creek, and later investigations showed that they reached as far north as the head of Toro Creek, keeping near the summit of the range. The Cretaceous rocks outcrop in a direction at right angles to the strike across the creek below the old Padre Mine and part way up a high mountain on the northeast. In this direction strata are exposed which are lower in the formation, and are filled with calcareous nodules similar to those seen in the shale in several localities in Santa Barbara County. This mountain is quite precipitous to the south, and on the summit occur rocks of quite a different character. These rocks much resemble the Tertiary, though no fossils were found. Between the two formations a horizontal body of lava has been intruded in the form of a laccolite. The Cretaceous shales below are much broken for half a mile away, and for 200 ft. considerably baked, presenting bluish and greenish tints. The younger rocks above are also greatly broken, dipping in every direction, and the banded sandstone strata in near contact with the eruptive, show red, brown, and greenish tints. It seems probable that some of the shales directly below are also Tertiary. The lava is about 50 ft. thick in the center, thinning out at the extremities. It is quite porous on the edges and in narrow bands running horizontally through it, the pores being filled with calcite. Large crystals of feldspar appear in places in the dark, fine-grained rock.

The area of serpentine in the Santa Lucia, north of San Luis Obispo,

is very great, forming nearly the whole of the western slope of the range from the railroad tunnel northwest to Cayucos. It contains many chromic iron deposits, and is characterized by numerous bodies of diorite, generally in nodular form and from 2 to 3 ft. in diameter upwards.

The Miocene increases from small areas in the foothills of the range east of Morro, until back of Cayucos, near the summit of the range, where it is a mile and a half wide.

Toro Creek, which enters the ocean between Morro and Cayucos, was ascended to its head, and another complete section of the Santa Lucia range was made. For the first 6 miles up the creek the only rocks seen belonged to the pre-Cretaceous series, consisting chiefly of sandstone and jasper. At the base of the first high range, which consists of serpentine, there is a small area of Miocene. Northeast of the serpentine range, through which the stream has cut a narrow gorge, is a trough about 2 miles wide filled with black shale and a little sandstone, dipping northeast at a small angle. In one of the beds of coarse sandstone were found large, excellent specimens of *Aucella*. They occurred, perhaps, a thousand feet from the exposed base of the shales. Northeast of this Cretaceous valley is another range of serpentine, diorite, sandstone, and jasper. On the northeast slope rest heavy-bedded sandstones, probably of Chico age. These dip northeast at an angle of 40°. At the foot of the mountains the sandstone is followed by nearly horizontal Miocene strata, bituminous slates extending easterly to the Salinas River. Small patches of Miocene also appear near the summit of the eastern crest of the range just described. *Fig. 12* gives a section of the mountains at this point.

Between Templeton and Cayucos, a section farther north, no Lower Cretaceous strata appear, while Miocene shales are strongly developed on the west, extending up to and forming the crest of the range. The dip is to the southwest at a high angle. A dike of diabase, at present very much decomposed, has been intruded in them below the summit on the western slope. The summit of the mountains is broad here with a rolling surface, while here and there the pre-Cretaceous rocks project up through the Tertiary. The Chico extends up to the summit on the east. Everything points to the fact of the intrusion of the serpentine prior to the deposition of the Chico. The altitude of the range at the two cross-sections just given is about 1,400 ft.

With the exception of a small area of Miocene at Point San Simeon, and of Cretaceous south of Cambria, the rocks of the pre-Cretaceous series with decomposed eruptives form the coast-line for many miles north from Morro Bay. The greater portion of this older series consists of sandstone. It is not a very quartzose rock, and in decay produces a heavy soil. Beds of shale or slate appear interbedded with the sandstone. Jasper is not abundant along the coast, but in the higher ranges is very characteristic. There are several classes of eruptives. One has a greenish-gray or brownish tint, is fine-grained, and greatly decomposed. These rocks appear near Cayucos, between Cambria and San Simeon, and at various other points along the coast. There are numerous outcrops of serpentine near the coast, but the areas of greatest extent are found higher up in the range. Liparite outcrops on Santa Rosa Creek north of Cambria, near the summit of the range 6 miles east of Cambria, on San Simeon Creek a mile from the ocean, and at several other places in the vicinity of Cambria. It also forms a number of

rugged peaks on the summit of the Santa Lucia. The highest of these peaks lies back of San Simeon, and is known as Pine Mountain. The liparite is undoubtedly the youngest of the eruptives in this region.

The strike of the pre-Cretaceous series is irregular—from Morro to San Simeon perhaps more often east and west, though sometimes parallel to the coast; dip very irregular. North of San Simeon the strike runs parallel to the coast and the dip is to the northeast at a small angle. Only a slight metamorphism is shown. The argillaceous rocks, which if not for the crushing undergone would be present as slate, are either represented by shale or clay. When the mechanical forces have been particularly strong the sandstone strata have been crushed and the shale, or rather clay, has been squeezed around the fragments so as to envelop them.

A belt of Miocene slates begins at Point San Simeon and extends northwest. It gradually passes away from the coast, forming low hills between the more mountainous portions of the Piedra Blanca grant and the ocean. It terminates in scattered patches 14 miles northwest of San Simeon, near San Corpojoro Creek. At San Simeon it dips oceanward at a high angle. Another cross-section of the mountains was made between Cambria and Paso Robles. Five miles east of Cambria the creek has cut through a dike of feldspar porphyry, leaving high cliffs on either side. Eight miles east the Miocene appears capping the hills. This strip of Tertiary continues northwest as far as the southern portion of the Piedra Blanca grant, and in a southeast direction connects with the great body of rocks of the same age on the summit back of Cayucos. The thickness of the strata is not great east of Cambria, and it seems strange that this section should have been selected as a suitable place to bore for oil. Eight miles east of Cambria, near Mr. Lehman's place, a well was put down nearly 700 ft., when a crystalline rock was encountered. The Tertiary rocks here are much disturbed by dikes of diabase, and it is probable that one of these was struck. This diabase is well exposed in a cañon near the Oceanic Quicksilver Mine. Four dikes of very greatly decomposed rock appear as intrusive in the Miocene. The strata have been thrown into a vertical position and considerably metamorphosed. Two of the dikes are each nearly 300 ft. wide. At the foot of the grade on the head of Santa Rosa Creek these dikes were encountered again. Here they are more decomposed still, with the development of a concentric shell structure. The nodules are, many of them, a foot in diameter, with very even, regular shells a quarter of an inch thick.

The usual series of shales, sandstone, and jasper forms the main portion of the Santa Lucia at this point. Patches of Tertiary extend up nearly to the summit on the southwest, while beginning only a short distance down on the northeast, the Chico sandstone and shale have a width of several miles. Below them is a lesser range of the older rocks, in which the Santa Cruz Quicksilver Mine is situated. East of this the Miocene slates underlie the whole country, except for a submerged axis of granite through the Salinas Valley. This granite axis is the prolongation of the crystalline axis of the San José range. It appears in places from Paso Robles northwestward along the divide between the Nacimiento and San Antonio rivers, finally joining with the more rugged portion of the Santa Lucia. The Miocene is almost undisturbed except on its very western

edge, as shown along the road from the Santa Cruz Quicksilver Mine to Paso Robles. Near the granite it changes to a loose quartzose sandrock. The course of the hidden granite axis can be traced by this sandrock.

A shaft was sunk for coal near the mouth of San Simeon Creek many years ago. Thin seams only were found and the work was given up. The coal is found in rocks which are supposed to belong to the pre-Cretaceous series, and it is the first instance which has come to the writer's attention of coal in that series of rocks in California. The low hills along Pico Creek are capped with a soft rock, probably Miocene. Near the head of the creek on the southeastern side of the Piedra Blanca grant there is a considerable thickness of a rather soft sandstone of unknown age, in which a small seam of coal has been found. The summit of Pine Mountain, as before stated, consists of liparite. Around its borders and apparently underlying it is a body of black shale, dipping to the northeast. The liparite is several hundred feet in thickness, and was once much more extensive. The underlying shale being soft, was worn rapidly away and the liparite has broken off in large masses, which strew the mountain sides and are piled in the cañons fully a mile away. On the grade leading up to the old sawmill specimens of *Aucella* have been picked up, and one is in the possession of the Mining Bureau. This gives the age of the shales as Lower Cretaceous. Serpentine apparently cuts the shale, but that could not be stated definitely, for no good contacts were seen. *Fig. 13* is a section of the Santa Lucia through Pine Mountain. From this point northward the Santa Lucia range has an elevation of fully 3,000 ft., and is very wild and rugged. North of San Simeon the range approaches the ocean, and north of San Corpojoro Creek but little agricultural land is to be found. The high mountains closely border the coast all the way from this point to Monterey, much of the distance rising very precipitously. But few small patches of land sufficiently level to be cultivated exist. Most of the mountain slopes facing the ocean are free from brush and are used as grazing land. A rough trail follows up the coast, and owing to the numerous deep cañons which it has to cross, is an exceedingly difficult and somewhat dangerous one to travel.

The pre-Cretaceous series, though it becomes more metamorphosed in portions of this lofty region, contains in general few intrusive masses. It is characterized by more or less silicification, and in the west central portion of the county (the Cruikshank District) the quartz veins are numerous and often rich in gold. However, it may be remarked that the gold-bearing quartz veins are not confined to this district, but from the center of Santa Barbara County northward through the whole length of the coast ranges, wherever this formation occurs there is more or less silicification, and at numerous points quartz veins carrying iron sulphides and traces of gold are to be found. In the cañon of Salmon Creek 3 miles above its mouth much prospecting has been carried on. The veins occur in a rather broken rock consisting of sandstone and shale. About half a mile south of these prospects, on the divide between the two forks of Salmon Creek, there is exposed the most remarkable bed of slates yet seen in this part of the coast ranges. The belt extends easterly, it is reported, for several miles. The dip is north away from a great serpentine ridge. The slates cleave well and have evidently escaped the effects of crushing which is so generally to be seen. In the shining black appearance and manner of weathering they closely

Fig. 13.

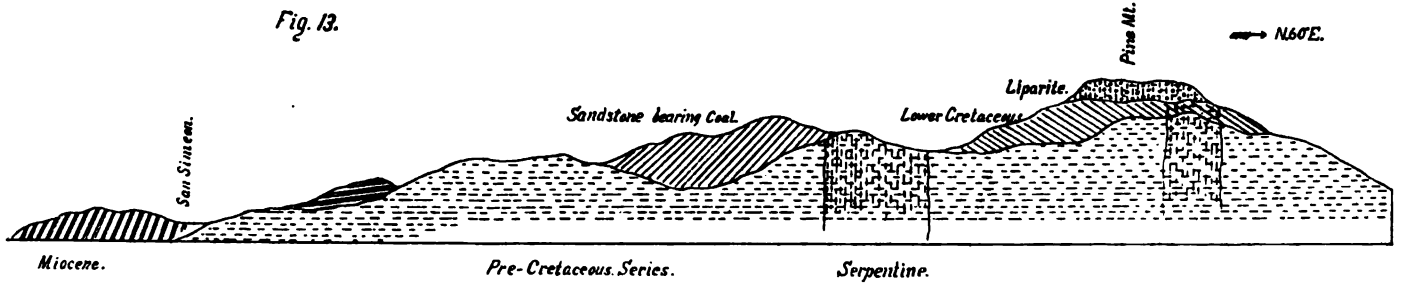


Fig. 14.

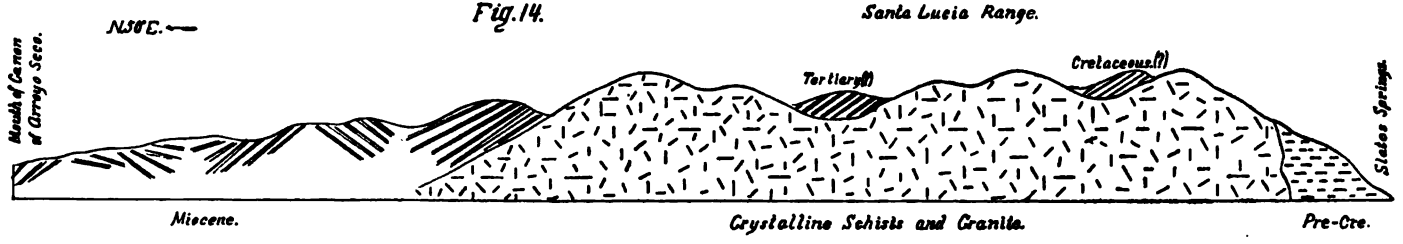
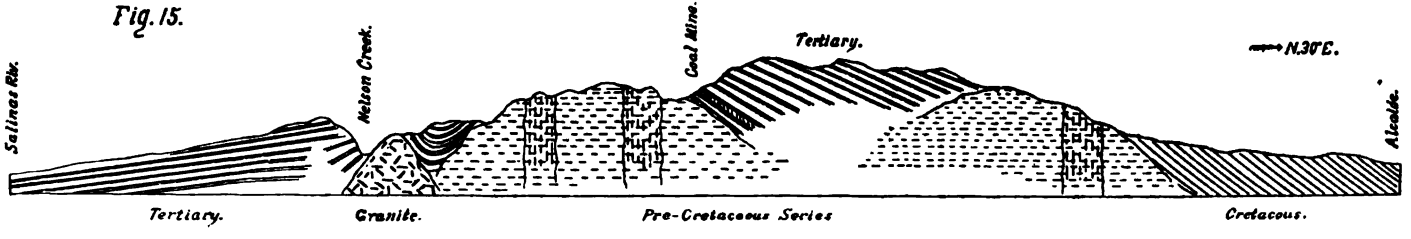


Fig. 15.



resemble the Mariposa slates along the Mother Lode. Time did not permit of the search for fossils in this slate, but the chances for finding them here are much better than in most of the argillaceous rocks which have been so much distorted. The serpentine on the south contains many great bunch-like masses of diorite. Dark, fine-grained eruptives of various kinds outcrop in the cañon of Salmon Creek.

From Salmon Creek to the Cruikshank ranch the trail follows in the strike of the rocks, the shales and sandstones dipping generally to the northeast. The Cruikshank Mines lie at an altitude of about 2,700 ft., nearly on the summit of the range. No intrusions of any kind are to be found near the mines. The formation is sandstone chiefly, with some shale, and is very much broken. About 2 miles west of the mines the mountains rise somewhat higher and very precipitously from Point Gordo. Here is a considerable outcrop of a decomposed amygdaloidal lava, the region being known locally as the "Volcano." The lavas were traced for several miles to the southeast past the Cruikshank ranch. Two miles south of Pacific Valley a heavy body of serpentine forms a bold projection into the ocean. From Pacific Valley north to Mill Creek the trail follows near the ocean. The rocks are much metamorphosed and contorted, beautifully banded jasper appears, as well as semi-crystalline schists and sandstones, which are crumpled and filled with quartz veinlets in a manner quite similar to the rocks along the summit of the coast ranges in the western part of Tehama County. From the Cruikshank Mines the trail leads eastward to the Newhall ranch and Jolon. The pre-Cretaceous series has a width of 10 miles. The only eruptives seen on this trail were a dike of serpentine and a small one of glaucophane schist. Sandstone, shale, and jasper form the prevailing rocks. The last ridge, bordering the Nacimiento on the west, consists of the Chico dipping to the northeast. The basal portion rests on the pre-Cretaceous series. It is a coarse, feldspathic sandstone, followed upwards by shales, sandstone, and conglomerates. The sandstone dips under the valley of the Nacimiento and rises again on the eastern slope of the hills between it and the San Antonio River, dipping from these hills to the southwest. The river thus flows in a synclinal, which becomes very narrow at the upper end of the Newhall ranch, where the river issues from the cañon. This sandstone appears for several miles up the cañon, finally giving place to crystalline schists, which from this point northwestward form the main part of the Santa Lucia range. This is not, however, the most northerly point reached by this Cretaceous arm, for it forms much of the very rugged country on the head of the San Antonio, extending over the divide between it and the Arroyo Seco, and outcrops at least as far north as the point where the trail crosses the range from Slate's Hot Springs to the Arroyo Seco. Fossils are reported from this latter locality. These Chico beds are not known to extend over onto the ocean slope of the range.

The submerged granite ridge extending northwest from Paso Robles crops out on San Marcos Creek, 6 miles southwest of San Miguel, at several points between this locality and Pleyto, and again between the Newhall ranch and Jolon. Northeast of the latter point this granite axis rises to form with crystalline schists the main portion of the Santa Lucia range. The schists replace the granite north of the Newhall ranch, and with limestone form the high mountain about the head of the Nacimiento. Over the divide they extend about half way down to

the ocean, where they are replaced by rocks of the pre-Cretaceous series. As exposed along Vicente Creek, this latter series rests unaltered against the crystalline complex. The latter in this vicinity consists of mica, hornblende, and chloritic schists and quartzite, with many bodies of crystalline limestone. Dikes of granular character, consisting of quartz and feldspar, also those of very coarse hornblende and feldspar, with others of a more basic character abound. The pre-Cretaceous rocks near the contact are crushed and filled with quartz veins. The limestone is very highly crystalline, and in many places is characterized by the presence of molybdenite, pyroxene, and a golden-colored mica. Garnets are very abundant in the schists in this portion of the Santa Lucia. The limestone increases in amount toward the northwest, and on Mill Creek is enormously developed. It extends from the summit of the mountains at an elevation of 4,000 ft. down Mill Creek to within half a mile of the ocean. It is often interstratified in the schists in bodies of no great size, but beds apparently several thousand feet in thickness appear in the higher portion of the range. They apparently extend through a vertical distance of many thousand feet of schists. Mountain movements have subjected the rocks to such strain that the limestone beds are broken into innumerable fragments, so that in getting out rock for the Rockland Lime Company, whose limekilns are located on Mill Creek, no solid unbroken beds could be found. The whole side of the cañon appears to be formed of a loose aggregate of angular limestone fragments. The limestone beds lie in the form of a V, extending down nearly to the ocean on the South Fork of Mill Creek, and retreating again to the summit of the mountains in the direction of the head of the North Fork. The limestone appears in enormous masses on the summit east of Big Cañon. They were examined nearly to Hot Springs Creek, and are reported to extend northward as far as Pico Blanco, a prominent mountain back of the Sur. The limestone is everywhere exceedingly metamorphosed, and though examined carefully in many places not a trace of life was detected.

Considerable metamorphosed rocks of various kinds, together with decomposed eruptives, outcrop along the ocean near the mouth of Mill Creek. It was not determined certainly to which series of rocks they belonged. The crystalline schists retreat toward the higher mountains north of Mill Creek, and there is a corresponding expansion of the pre-Cretaceous series, sandstone, including dikes of serpentine, appearing nearly half way to the summit. It was noticed that without exception the eruptives characteristic of the pre-Cretaceous series do not appear in the crystalline rocks, although it would seem in places that the eruptive must be intrusive in them below the surface. South of Big Cañon the sandstones of the older series were seen resting on the granular chloritic schists without exhibiting any metamorphism, thus demonstrating conclusively the great break between the two formations. Except for two small outcrops of limestone north of Salmon Creek, none was seen in the pre-Cretaceous series in this part of the State, while the limestones of the crystalline complex were seen to extend up to the contact and no farther. South of Big Cañon, and between the pre-Cretaceous series and the coast, is a strip of dioritic rocks through which the creek has cut a deep and narrow gorge. On the north fork of the creek, below Dolan's Hot Springs, occur serpentine shales and sandstones, and above them the granitic rocks.

From Big Cañon the narrow strip of pre-Cretaceous extends up the coast to and past Slate's Hot Springs. In fact, the series is reported to reach as far north as Point Sur. The strip is less than a mile wide, and consists of shales, sandstone, and jasper. The series terminates at the base by a conglomerate resting against the crystalline schists. The dip is either a very steep one away from the range, or, as it is in places, into the range. The conglomerate has a thickness of several hundred feet, but its extent along the coast was not traced out. The bowlders are all smoothly washed, and the most of them consist of a chloritic granite or gneiss similar to that in the mountains above them. The sandstone matrix is so metamorphosed as to very closely resemble a crystalline rock. At Slate's Springs the conglomerate is followed upward by sandstone, slaty shale, and jasper. The whole series is considerably metamorphosed, and all the members filled with ramifying quartz veinlets. The shale in its metamorphism has assumed the appearance of a fine-grained mica schist. Fragments of a fossil shell belonging to the genus *Inoceramus* were found in the cliffs at the hot springs. The specimens were, however, very poorly preserved, on account of the shaly nature of the inclosing rock, and nothing definite could be made out about them. The basal conglomerate settles conclusively the greater age of the crystalline schists, and probably of the granite also. In addition to the coarse, fresh-looking granite and gneiss of the Santa Lucia range, there are large bodies of granitic rocks with a chloritic constituent in the place of the mica, and which are probably much older.

A very interesting thing in connection with the study of the crystalline schists and the pre-Cretaceous series resting on them, is the fact that not the least sign of the contact is noticeable from a study of the topography. In fact, the whole Santa Lucia range is an anomaly in this regard. The range is unbroken by any low passes indicative of the changing formations. The change in topography from Tertiary to Cretaceous, and from Cretaceous to pre-Cretaceous, is only slightly noticeable, while the pre-Cretaceous laps onto the crystalline schists, gradually thinning out toward the north.

The San Antonio Valley is separated from the Salinas by a line of Miocene hills known as the San Antonio Hills. Rocks of the same age also close in the valley on the north, forming the foothills of the Santa Lucia Peak. Six miles above the old mission the San Antonio River cuts through a ridge of crystalline rocks, above which another small valley opens out, having on its northern side extensive Miocene shales. The whole of the Miocene, as far as was noticed in this section, dips to the northeast at an angle of about 45°. The last great elevation seems to have been to the southwest.

The Arroyo Seco is a large stream which cuts nearly across the Santa Lucia range. Miocene rocks are the only ones exposed for about 10 miles above the mouth of the cañon. They are folded together and contorted into every conceivable position. At Abbotts the last of the Tertiary is seen resting on the crystalline schists. The latter consist of mica and hornblende schists, varying to gneiss, and intersected very generally by veins of granitic matter. From this point to the summit there is very little variation in the character of the rocks. In places they become almost granitoid. Portions, at least, of San Lucia Peak, the highest mountain in the range, are formed of the coarse white porphyritic granite like that at Monterey. Beginning on the Arroyo Seco,

about 3 miles below the Tassajara Springs, sandstone of supposed Tertiary age is exposed in a long shallow deposit extending several miles to the northwest. It dips about 40° to the northeast.

North of the Arroyo Seco the eastern portion of this mountainous region is known as the Soledad Hills. They form a very high and regular mountain wall on the western side of the Salinas Valley for about 25 miles. They are separated from the main portion of the Santa Lucia by the valleys of the upper Carmel River. This range of hills has an elevation of 2,500 ft., and consists of crystalline schists, with occasional bodies of limestone. The Miocene slates extend over the divide from the Arroyo Seco to the Tularcitos, forming the valley of that stream down to its junction with the Carmel, and finally connects with hills of the same age east of Monterey. Mount Toro, at the northern end of the Soledad Hills, shows a considerable body of granite, while the crystalline schists in the region about are filled with granitic dikes. *Fig. 14* gives a section through the Santa Lucia in the region of the Arroyo Seco.

Between Paso Robles and the southern Cholame Valley undisturbed beds of late Tertiary age appear. It is on the east of this valley that the pre-Cretaceous axis of the Mount Diablo range first appears. The pre-Cretaceous series gradually rises from beneath the Tertiary north of Polonio Pass, and forms a ridge of 3,000 ft. elevation north of Parkfield. The Tertiary rises high on both sides, in places capping it, as in the region about the head of Stone's Cañon. The characteristic rocks of the older series are all well represented in this range. They consist of sandstone, shale, and jasper, with eruptives, among which are serpentine and glaucophane schist. The Cholame Valley is bordered on the southwest by Miocene hills. In the edge of the valley, at the base of these hills, is an outcrop of granite, which has been so crushed and decomposed that it can hardly be distinguished from the granitic sandstones adjoining. The granite does not appear prominent, but its position is indicated by a series of soft sandhills extending to the head of the valley. Granite associated with limestone outcrops along Nelson Creek for 2 miles. Both the limestone and granite have been brecciated and the fragments re-cemented. The overlying formation is a soft gypsum-bearing clay, followed down Indian Creek by sandstone and the typical bituminous slate series. Above the Tertiary clays, which are in contact with the granite on the east, rises the main range. On its western slope are large areas of typical banded jasper, showing a fine, wavy structure. The summit is capped by Miocene sandstone and shale, dipping to the northeast at a high angle, and containing the Slack Cañon coal beds. As we descend the northeastern slope from an elevation of 3,500 ft. the pre-Cretaceous series is again encountered and continue down to Carey Creek. Walton Cañon has a length of 6 miles, giving an excellent exposure of sandstone and shale of probable Cretaceous age. The strata dip easterly at an average angle of 50°, exposing a thickness of nearly 20,000 ft. *Fig. 15* gives a section of the range at this point.

A great thickness of similar strata appears south of Los Gatos Creek. The pre-Cretaceous series outcrops quite prominently on the southern end of the range of which San Carlos is the dominating peak. It also appears in the mountains along the eastern side of the upper San Benito. West of the river the formation is chiefly Tertiary; farther down

the river cuts through the high range, of which Hepsedam is the culminating peak. The axial rocks of this range belong to the pre-Cretaceous series. Below the point where the river cuts through this range, the flanking hills are all Tertiary. They rise in places in bold cliffs facing the river.

West of New Idria is one of the largest areas of serpentine known in the coast ranges. The features which its surface presents are quite

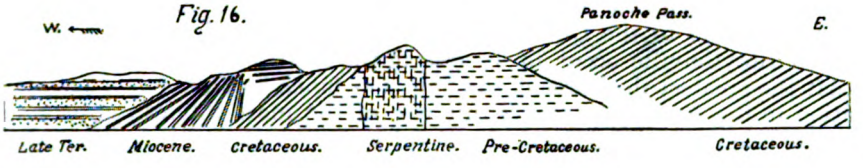


Fig. 16.

unusual. Owing to some peculiar manner of decomposition the surface has been so softened that it appears in the form of rounded clay hills, often entirely free from vegetation of any kind. Rising out of these hills are occasionally to be seen mineralized portions carrying quicksilver. All the streams heading in these mountains are strongly impregnated with magnesia. Small areas of the pre-Cretaceous series appear about New Idria. To the east are barren hills in which the stratification of the Chico-Tejon is very finely shown. The Chico-Tejon appears well developed along the divide west of Panoche, the road to Tres Pinos crossing it for several miles. Lower down on the Tres Pinos Creek jasper and sandstone of the pre-Cretaceous series outcrops in a low ridge through which the creek runs in a cañon. The sandstones are crumpled and filled with quartz veinlets. Below these rocks is a small outcrop of dark shales, probably Cretaceous. In the hills on the sides of the cañon the Tertiary appears to rest unconformably on the dark shales. A short distance down the cañon the Tertiary has been folded in and stands almost vertically. The dip becomes less as we go down the cañon until it is almost horizontal. Beds of probable Pliocene age follow. The latter consist of but slightly cemented bowlder deposits, sandstone, etc., and have been eroded so as to give magnificent exposures.

Fig. 16 gives a diagramatic sketch of the mountains along the road from Panoche to the San Benito. In the region about the Los Muertos

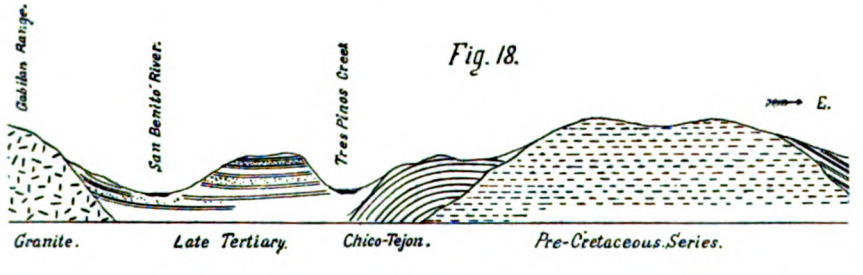


Fig. 18.

grant the pre-Cretaceous series forms the summit and the western slope for 15 miles in the direction of Tres Pinos, when it becomes covered by sandstone of probably Chico age. A section across this range to the Gavilan is shown by *Fig. 18*. Going north from this point up

the Arroyo Joaquin Soto the older series disappears and its place is taken by high and rugged mountains on both sides of the valley, formed of liparite lying in nearly horizontal bands, and lesser amounts of more basic lavas. This volcanic country culminates in the San Juan Peaks over 3,000 ft. high. At this point the volcanic rocks have a width of 8 or 10 miles. They have a thickness as exposed in the mountains bordering the Joaquin Soto of fully 1,000 ft. The lava is exposed nearly to the foot of the grade on the road from Staytonville to Hollister. At its lowest exposures it is shown to rest on shales and sandstone probably belonging to the Chico. The antimony and quicksilver deposits about Staytonville occur in fissures in the liparite. It seems probable that the greatest thickness of the flow is as much as 1,500 ft. The variation in the lavas here makes this one of the most interesting regions in the coast ranges for the study of volcanic rocks.

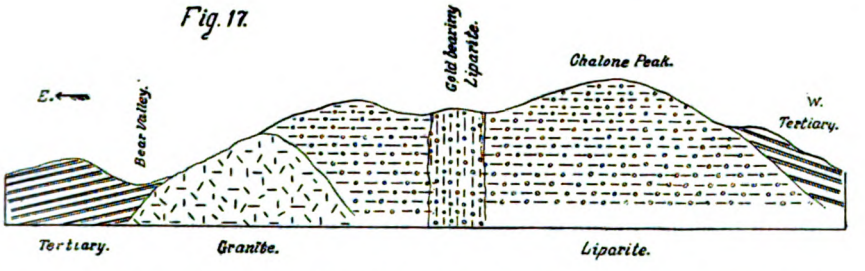
The Gavilan range is essentially a granitic one. It is evident that the granite on the west of Cholame Valley and in the cañon of Nelson Creek belongs to the southeast prolongation of this axis. This seems probable, not only from position, but from physical characters. Granite detritus is abundant in Slack's Cañon, while farther to the northwest there is another link, the granite outcropping prominently in the cañon of Lorenzo Creek, below Lone Oak. The greater portion of the latter exposure is a massive granite with glassy feldspars and small crystals of titanite. Granite appears again on Chalone Creek at the eastern base of the peaks, but the southern portion of the Gavilan range proper begins about 8 miles north of the peaks. Opposite Gonzales the granite has an exposed width of about 6 miles. The granite outcrops nearly to the base of the range on the Salinas side, while on the northeast, between it and the San Benito, are extensive Tertiary beds, consisting largely of granitic detritus, and extending in places nearly to the summit. As the range is followed northward the granite widens and, associated with crystalline limestone, extends down to the San Benito River, near Willow Creek. The limestone so prominent in this range crosses it slightly diagonally, beginning as just mentioned on the eastern slope near Willow Creek; the beds extend to and over the highest portion, Fremont Peak, and down on the western side. The beds are not continuous, but appear as kidney-shaped bodies. They vary from coarse to finely crystalline. The limestone, though fully as much metamorphosed as that in the Santa Lucia range, is very free from impurities.

North of Peach Tree Creek the pre-Cretaceous series is well developed, consisting of red and brown jasper, sandstone, glaucophane schist, and intrusives of varying character. A small area of these rocks was noted in the hills west of San Benito P. O. In fact, this series probably underlies much of this region which is now covered by the Tertiary, judging from the scattered outcrops which appear so irregularly. The granite axis of the Gavilan has been the scene of the eruption of a number of masses of acid lavas. The most southerly one exposed is about 4 miles west of Parkfield, on the borders of Cholame Valley. There the lavas are all fine-grained and stony, with interstratified layers of obsidian. The rock is evidently acid enough to be classed with the liparites.

The Chalone Peaks form the southern termination of the Gavilan range. The south peak lies at the western extremity of a body of both massive and banded liparite which stretches north for about 6 miles,

with a width of 2½ miles. The peak has an elevation of about 3,000 ft., descending very abruptly to the west and south, and gradually to the north. Although the whole body seems to belong to the acid series, yet there is a great variety of crystallization products. Obsidian is abundant on the peak as well as in a cañon on the eastern side of the flow. This liparite is particularly interesting on account of containing gold, apparently as an original constituent. There are no signs of a crater, for the amount of erosion since the flow took place must have been enormous, yet everything points to the fact that the matter welled up through fissures, not all at once, but under different conditions and at different times. An immense mass of volcanic tufa stretches along the western side of the solid lavas. It forms the north Chalone Peak, which rises fully 100 ft. higher than any present existing lava. The extent to the north is about 8 miles, considerably beyond any of the lava in place. The tufa dips west at an angle varying from 30° to 60°. The northern portion has been eroded into deep cañons and high jagged pinnacles,

Fig. 17.



rising hundreds of feet. One fork of Chalone Creek has cut across the tufa, exposing cliffs nearly 600 ft. high, and which, owing to some peculiarity of structure, weather vertically. The total thickness of the tufas cannot be less than 6,000 ft. They are made up wholly, except at the base, where some granitic gravels are mixed with the volcanic, of more or less rounded bowlders of the lava, cemented by a sand of the same material. The relation to the Tertiary indicates that the lavas and tufas are older. *Fig. 17* gives a section of the Chalone Peaks.

Another eruption of liparite appears at the northern end of the range, extending from Mr. Flint's ranch over the summit where the old stage road crosses and some distance down on the western slope. This has a uniform coarse texture. Where the road crosses, the liparite appears to be intruded through sandstone, which is probably of Chico age. The sandstone is much metamorphosed near the liparite and steeply inclined.

SUMMARY OF THE VIEWS DISCUSSED IN THE FOREGOING NOTES.

There exists in the central and southern coast ranges granitic axes associated with crystalline schists and metamorphic limestone, all of unknown age. Structurally, the crystalline axes, more particularly that represented by the San José, Santa Lucia, and intermediate occurrences, are the northwest prolongation ef the San Emedio range. Tentatively, it may be assumed that the crystalline schists and limestones are of Palæozoic age, and the intruded granite of the same age as the greater portion of the San Bernardino and Peninsula ranges. These rocks are

the oldest known in the coast ranges and form the basement complex upon which the other formations have been successively laid down.

Topographically these ancient rocks are not prominent, save in a few cases, but constitute what might be called a depressed mountain system, of which only the more prominent portions project through the later coverings. It is probable that during early Mesozoic times this mountain system was far more elevated than at present, and that before the lowest uncrystalline sedimentary rocks which have been found were deposited, there was a long interval of erosion, following which a subsidence took place, which was so extreme that very little, if any, land existed through the coast ranges. Following this event the formation which has been variously termed the Metamorphic, Metamorphic-Cretaceous, and pre-Cretaceous, was deposited. Through an extent of 500 miles, and perhaps more, from southeast to northwest, the sedimentary rocks of this series appear. They consist of jasper or phthanite, gray sandstone, conglomerate, and shale or slate when not deformed by crushing. The series has been somewhat metamorphosed, particularly toward the north, where appear mica and hornblende schists. The characteristic metamorphism of the series as a whole, and one which distinguishes it lithologically from all the other formations of the Coast Range, is a chemical one, more pronounced where dynamical effects have been strongest.

This consists in a silicification of all but the softest and more impenetrable argillaceous rocks in the form of interlacing quartz veinlets from microscopic size upward. This is evidently the result of an intense crushing together of the sedimentary strata as well as of the underlying crystalline rocks, filling them with innumerable fractures, through which silicious solutions from the deeper-seated acid rocks percolated; the chemical action being induced on so large a scale by the heat generated, which, however, was not sufficient to produce fusion. Very rarely in the coast ranges is this peculiar metamorphism apparent in any of the succeeding formations, save in the immediate vicinity of the hot springs in the quicksilver regions. The silicification is more pronounced in the harder and more brittle strata. The crushing was so intense that over much of the region under discussion no system of regular folds has yet been made out. The more brittle strata have been fractured, the pliable contorted, and the soft crushed. As this regional silicification has been demonstrated on good evidenee to be confined to a series of rocks underlying unconformably the Knoxville, the lowest recognized Cretaceous, and as this boundary line between the Lower Cretaceous and the Upper Jurassic is supposed on good evidence to represent the period of intrusion of the great mass of Mesozoic granite of the Sierra Nevada, it seems highly probable that an action of so intense a character in the adjoining range was the accompaniment and partial agent in the elevation and crushing together of the Coast Range axis, resulting in the silicification described. As far as we yet know this important mountain movement in the coast ranges was not accompanied by granite south of the Klamath Mountain region.

This series of rocks so strongly marked, lithologically, is also characterized by great numbers of intrusives, which are not known to penetrate any of the younger formations. These have undergone the same deformation as the series through which they were erupted, and in most cases their original character cannot be determined by the unaided eye.

All that we can say of them is that they are older than the Knoxville, and, perhaps, in part, antedate the period of intense dynamical metamorphism. Although they may not differ in composition from the eruptives in the Cretaceous, yet, in their present physical character, are generally quite easily distinguished.

Mr. J. S. Diller has recently obtained good evidence that the whole body of Cretaceous north of the 40th parallel is one continuous series of sediments without important physical break. Although to the south no such systematic study of the Cretaceous has been attempted, yet it would seem highly probable from the evidence at hand that the same conditions which obtained in the northern coast ranges during the Cretaceous must have existed without any great modification throughout the whole extent of those ranges. The writer believes that as far as the geological history of the Pacific Coast has been unfolded, no important mountain movements have been shown to be local. Consequently, in studying the rocks of Cretaceous age through the central and southern coast region, wherever we find any portion of the Cretaceous resting unconformably on a basement series of different character, and more or less metamorphosed, it may, with reasonable certainty, be postulated that such a break is good evidence of at least a pre-Knoxville series, and if the Knoxville be continued to be considered the base of the Cretaceous, then of a pre-Knoxville series. Not only have excellent examples of this pre-Knoxville unconformity in the region studied by Mr. Diller, which are included by him in the Klamath Mountains, but also only a short distance to the south in Lake and Napa counties the same has been noted by the writer; while fully 400 miles to the southeast, in almost the extreme southern portion of the coast ranges proper, in the cañon of the Santa Maria, the same unconformity has been noted. Many almost as strongly marked occurrences of a similar nature were observed in San Luis Obispo and Monterey counties. In fact, Dr. Becker, in studying the geology of the New Idria District, demonstrated that the Chico rests unconformably on an older formation, which he considered Lower Cretaceous, but which, in the light of Mr. Diller's studies, as well as those of the writer, must be referred to a pre-Cretaceous series. This proof for the existence of a pre-Cretaceous series should not be, and is not, based on the fact of the Chico having been found unconformable above an older series, for, according to the opinion of the writer, a small unconformity exists in the Cretaceous, but upon the strongly contrasted lithological character.

There is one fact which has been seemingly overlooked in a study of the Cretaceous, and that is the presence in it of innumerable bodies of serpentine from Santa Barbara County to the Oregon line. It is found, according to all recorded observations, to penetrate the pre-Cretaceous basement rocks in both coast ranges and Sierra, and wherever the Knoxville is present that too has been intruded, but the writer cannot find any record of its having been found in the Upper Cretaceous. This fact must necessarily indicate a considerable disturbance at some time during the Cretaceous period. Judging from the physical character of the serpentine, as well as its position stratigraphically, it must have been intruded at about the same time over a large part of the State. In San Luis Obispo County the serpentine occurs intrusive in *Aucella*-bearing shales, but in a number of instances it was distinctly seen to underlie the Chico.

The Lower Cretaceous is generally characterized by dark shale and a subordinate amount of sandstone, conglomerate, and small bodies of of limestone, while in the Chico sandstone and conglomerates predominate.

Succeeding the uplift, crushing, and metamorphism of the pre-Cretaceous, a subsidence took place, which, without any break save for the eruption of the serpentine, continued through to the close of that period. In Central and Southern California the sedimentation has been recognized as continuing through the Eocene, but in Oregon, according to Diller, a break separates the Cretaceous and the Tertiary.

At the close of the Chico-Tejon submergence in Central and Southern California but little if any land existed in the Coast Range region. Following the Cretaceous and Eocene in this region it is probable that a considerable elevation took place accompanied by a folding of this series. After a period of erosion a subsidence again took place to an extent almost as great as during the Cretaceous. On the eroded Cretaceous, pre-Cretaceous, and granitic rocks a great thickness of Miocene was laid down. This latter formation consists of sandstone, light-colored banded slates, and gypsum-bearing clays. At the close of the Miocene another upheaval took place, which elevated portions of the coast ranges over 5,000 ft. This is particularly noticeable in the southern coast ranges, in Santa Barbara and northern Ventura counties. Post-Pliocene movements have also been very pronounced.

[NOTE.—The term Chico-Tejon is used in this reconnoissance report for a series of beds, embracing the Upper Cretaceous and Lower Tertiary, which has yet been only slightly examined in the most of the region described. Chico fossils have been found in certain portions, Tejon in others; and while it would appear that paleontologically they are distinct, yet stratigraphically they seem to be continuous.]

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REVIEW OF OUR KNOWLEDGE OF THE GEOLOGY OF THE CALIFORNIA COAST RANGES

BY

HAROLD W. FAIRBANKS

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Scope of the Paper.

In the following article it is intended to set forth, so far as is possible with the information at hand, the present state of our knowledge of the geology of the Coast ranges of California. The central theme in the presentation will be a discussion of the evidence supporting the view of the pre-Cretaceous age of the uncrystalline basement rocks of this region. The evidence treated of will deal partly with some results of recent field-work in the southern portion of the area and partly with a more detailed restatement of the conditions found to obtain in northern California. A brief summary will also be made of the characters of the oldest rocks in the Coast ranges—the granites, crystalline schists and limestones—as well as of the Cretaceous and Tertiary formations, and of the disturbances which have taken place, as indicated by the relation of these formations to each other.

It is with no intention of putting forth categorical statements concerning disputed questions that this article is prepared, but of giving more definite and explicit reasons for some previous views published by the writer in the American Geologist.* Many of the opinions therein ex-

*American Geologist, vol. ix, 1892, pp. 153–156, and vol. xi, 1893, pp. 70–84.

pressed seem to him to have been more completely substantiated by the results of field-work since their publication.

Great misconceptions have existed in regard to the real geologic conditions existing in the Coast ranges, both as to their age as well as to their relation to the supposed older range, the Sierra Nevada, and it is hoped that some light can be thrown on these questions.

The Term Coast Ranges.

DIFFERENT GEOLOGISTS' CONCEPTION OF THE TERM.

The designation Coast ranges as applied to that series of mountains bordering the coast of California is a very indefinite one and, owing to the topographic features, one which it is difficult to make exact. The term was first used by Fremont* in 1843. The names current among the Spaniards were those of individual ranges or peaks.

Dr Trask, in the opening of his first report,† speaks of the Coast ranges as extending from the forty-second parallel (northern boundary of the state) to the Mexican line. Later he proposed to divide the coast mountains south of San Francisco bay into Coast ranges proper, lying to the west of the Santa Clara and Salinas valleys, and the Monte Diablo range bordering the San Joaquin valley. In another place he says it is proposed by Blake to apply the term Peninsula range to all those mountains south of the thirty-fifth parallel north latitude to distinguish them from the Coast mountains, as well as the Sierra Nevada. In his second report‡ he emphasizes his belief that the Coast ranges should be considered as terminating in southern San Luis Obispo county, and that the Santa Ynez range, rising from the sea at point Arguello and extending in a direction more nearly east and west, belongs properly to the San Bernardino sierra.

J. S. Newberry,§ one of the geologists of the Pacific Railroad Survey, expresses the following view:

"As far north of San Francisco as cape Mendocino the Coast mountains have the same general northwest trend, and a more plausible supposition than that the Cascades form a continuation of the Coast mountains would be that the latter ranges terminate at cape Mendocino, and that the Coast mountains of Oregon were a continuation of the Sierra Nevada. It is not necessary to suppose this, however, but it is sufficient to consider the Coast mountains of Oregon as the Coast mountains of California, deflected from the trend which they preserve below cape Mendocino, and that the ranges of the coast and of the interior inosculate on either side of the forty-second parallel in the Calapooya, Umpqua and Siskiyou mountains."

* Exploring Expedition to Oregon and California, 1843.
† State Senate Documents, no. 9, 1854.
‡ State Senate Documents, no. 14, 1856.
§ Pacific Railroad Survey, vol. vi, p. 29.

Blake says:*

"In California the term 'Coast mountains' is generally understood to refer to the several ranges of mountains lying west of the Sierra Nevada, extending from Oregon to point Conception, and forming the barrier between the long interior valleys of the Sacramento and San Joaquin and the Pacific ocean."

Professor Whitney† defines the Coast ranges as follows:

"We consider all those chains or ranges of mountains to belong to the Coast ranges which have been uplifted since the deposition of the Cretaceous formation; those, on the other hand, which were elevated before the epoch of the Cretaceous are reckoned as belonging to the Sierra Nevada."

He says further that between the parallels 35 and 40 degrees north latitude there is no difficulty in separating the Coast ranges from the Sierra Nevada, and that it is only on geological considerations that the lines can be drawn; that the topography gives no clue. On the north he considers the Coast ranges terminated by the Klamath and Trinity rivers, while on the south he would extend them to San Diego county, including the San Gabriel and Santa Ana ranges.

Jules Marcou‡ agrees with Dr Trask in that the Coast ranges should be considered as terminating in the southern part of San Luis Obispo county.

In Bulletin 33 of the United States Geological Survey, J. S. Diller says:

"For reasons hereafter given we will consider the northern end of the Sierra Nevada range to be in the vicinity of the North fork of Feather river before reaching Lassen's peak. From this point the elevation is continued for about fifty miles on the trend of the Sierras in the Lassen's peak volcanic ridge, which terminates near Pitt river. All south and west of mount Shasta belong to the Coast range. There appears to be a lack of appropriateness in including the ridges east of the Sacramento river, about the headwaters of the McCloud, in the Coast range, but it is evident that they are more closely related geologically to the Trinity and Scott mountains of the Coast range than to any portion of the Sierra Nevada."

He does not say whether it is used by him with the meaning simply of a topographic province, though that is the implication. In a recent note received from Mr Diller he emphasizes the statement that the term is used by him to indicate simply a "topographic province."

THE AUTHOR'S USE OF THE TERM COAST RANGES.

From the foregoing quotations it will be seen how difficult it is to frame an exact definition of the term Coast ranges. The definitions given vary greatly, being based partly on age and partly on topography. Further

* Ibid., vol. v, p. 138.
† General Geology of California, p. 167.
‡ Wheeler's Survey, 1876, p. 172.

on, the writer hopes to show the futility of attempting to frame a definition based on the age of the rocks, while it is evident at once that none can be given based on topography, because of the blending into other ranges at both ends.

The designation Coast ranges as it is used in the present article will include that series of mountain ranges extending west and northwest along the coast from the San Emidio region of crystalline rocks to and beyond the Oregon line. The San Emidio region, lying in northern Ventura county, is the meeting point of the Sierra Nevada and Peninsula ranges. In regard to the designation of the mountains in the northern part of the state, there seems to be no good reason for restricting the use of the term Coast ranges and substituting for it a local name. The usage of most of the earlier geologists is a good one, including, as they did, under the general term all that series of mountains near the coast, not only through California, but Oregon and Washington. Local names are perfectly proper and necessary for indicating particular sections, but because of the fact that there are included within the Coast ranges areas of such greatly different age, but not topographically distinct, no local or even general name can imply a geologic distinction. It would seem that the use of the term Klamath mountains is a convenient one and might well be adopted, but without implying any sharply marked geologic or topographic distinction. It would seem also that the use of the term Peninsula range for those mountains collectively which extend south from the San Emidio region into the peninsula of Lower California is a very convenient one.

South of the Santa Clara valley, in Ventura county, as far as the Santa Ana river, there are several mountain ranges the formation of which is largely Tertiary. These are, as a rule, not distinctly detached from the various mountains comprising the Peninsula range.

Summary of Previous Work.

The earliest extensive geologic work in this state was undertaken in connection with the Pacific Railroad Survey—Blake, Marcou, Antisell, and Newberry, geologists. Considerable study was given to the Coast ranges, particularly south of San Francisco.

A little later Dr Trask spent a part of two seasons working out the geology of the Coast ranges.

In 1860 the Geological Survey of California was organized, and work was carried on intermittently until 1874. The results of the work in the coast region is to be found mainly in the volume devoted to general geology and in the two volumes on paleontology.

The monograph on the quicksilver deposits of the Pacific slope, prepared under the direction of Dr Becker, was devoted mainly to the Coast ranges. In it we have the results of the first detailed work done in this region.

More recently the work of J. S. Diller has extended into the Coast ranges in northern California. Dr A. C. Lawson, of the State University, has also made valuable additions to the geology of the central Coast ranges.

Age and Relations of the Coast Ranges.

VARIOUS OPINIONS AS TO AGE.

There has not existed much diversity of opinion in regard to the age of the Coast ranges until recently. This series of mountains has been held by all investigators to be of geologically recent origin. Dr Trask recognized the granitic formation (primitive) and the Tertiary. He says:*

"That the shores of the Miocene sea were primitive is proved from the fact that these rocks are imposed directly on the latter, thus demonstrating that its relative age with that of the northern and eastern chains is widely different and far more recent."

Jules Marcou says:†

"What is the principal age of this system of mountains? In a word, at what geological epoch did it make its appearance? I now think as I did in 1854, when I saw it for the first time, that it should be referred to the end of the Eocene Tertiary."

Antisell,‡ in a foot-note, makes the following observation:

"The age of an axial rock combines the idea of the first upheaval through the hardened crust, and, to some extent, the period of its appearance above water, though not necessarily the latter idea. The Coast ranges were upheaved and lifted above the water posterior to the Miocene deposits."

Whitney states very plainly his ideas of the age of the Coast ranges in framing a definition for them; that is, that they date from the close of the Cretaceous. On page 16 of his volume on Auriferous Gravels he says:

"The most striking fact in regard to the Coast ranges is that this very extensive group of mountain chains is of comparatively very recent geological age. It is made up of Cretaceous and Tertiary strata, with no rocks older than these showing themselves in any portion of the complicated series of elevations which are properly included under the above designation."

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* State Senate Documents, no. 14, p. 19.
† Wheeler's Survey, 1876, p. 172.
‡ Pacific Railroad Survey, vol. vii, p. 24.

Dr Becker, while he has held that the granite and crystalline limestone may be older, has said that the upheaval between the Knoxville and Chico was the first distinctly traceable movement in the Coast ranges; and, farther:*

"The earliest determinable portion of the Coast ranges must then be considered as due to the same disturbance which added the gold belt proper to the Sierra Nevada."

H. W. Turner,† in a recent article reviewing the proposition advanced by the writer for the pre-Cretaceous age of the metamorphic rocks of the Coast ranges, offers the following hypotheses:

"1. That the granite, gneiss and metamorphic limestone of the Gavilan range and similar area elsewhere in the Coast ranges are Paleozoic and probably Carboniferous in age.

"2. That the phthanites, hardened sandstones and diabase are earlier than the Knoxville beds.

"3. That the serpentine, gabbro, and perhaps the glaucophane-schist, which is frequently associated with the serpentine, are post-Knoxville in age."

AGE OF COAST RANGES AS COMPARED WITH THAT OF THE SIERRA NEVADA.

As compared with the Sierra Nevada, the Coast ranges have universally been considered the younger. Dr Trask, however, regarded the granite as of the same age as that of the Sierra Nevada. The references in geologic literature all give emphasis to the views of a great age for the Sierra Nevada and a comparatively recent date for the upheaval of the Coast ranges. Nearly all investigators have recognized the presence of granitic rocks; yet they have generally been considered of small extent and to have played an insignificant part in the development of the system. A great age for the granitic rocks has been postulated by some, while others have considered them younger than the Miocene. This almost universal opinion as to the age of the Coast ranges must be based on some prominent geologic fact, and that undoubtedly is the great development of the middle Tertiary in the region south of San Francisco; and while Cretaceous as well as older uncrystalline rocks are present, they have not been distinguished from each other, and by some not even separated from the Tertiary.

PHYSICAL AND GEOLOGIC RELATION TO THE SIERRA NEVADA.

The chief difficulty in making an exact definition of the Coast ranges lies in the fact of the intimate geologic and structural relation to other mountain ranges, both north and south. Both Trask and Marcou in-

*Quicksilver Deposits of the Pacific Slope, p. 211.
†American Geologist, vol. xi. p. 324.

cluded in the San Bernardino sierra the Santa Ynez range of Santa Barbara county. This has its origin near point Conception, and, blending with the San Rafael and Cuyamas mountains, extends eastward as a high and rugged range to unite finally with the San Emidio mountains.

Antisell* concluded, from the great elevation of the Miocene on the flanks of the Cordilleras (the San Gabriel and Sierra Libre ranges, terminating on the northwest in the San Emidio region), that the date of upheaval was the same as that of the Coast ranges. It seems to the writer that in the following quotation he expresses a truth the real significance of which has never been appreciated. He says:

"Nothing appears easier to trace than the relation of connection and continuity between the middle of the Coast ranges (San José and point Pinos) and the San Emidio, and between the San Emidio and the Cordilleras, a fact now for the first time stated and brought to light by the exploration of this survey, by which there has been traced a continuous granite chain from point Pinos, at Monterey bay, to the northwestern edge of the Cajon pass, terminating at the Kikel Mungo mountain."

This granitic chain to which he refers, although it was not found to be continuous on the surface, seems to represent a single axis. There is little doubt that future work will prove the unity of the whole body of granitic rocks and crystalline schists along this very regular northwest prolongation of the Peninsula range.

According to all observers, no topographic distinction can be made in the northern part of the state. Beginning at San Francisco bay, there is a gradual rise in the mountains northward to the Yallo Bally and other ranges in Humboldt and Trinity counties.

Rocks of the Region and their Relations.

The wholly crystalline basement complex.

Constitution and Distribution.—The basement rocks in the Coast ranges consist of granite, crystalline schists and limestone. The exposed area of these rocks, although considerable, is small in comparison with the extent of this mountain region, but the part played by them in the development of its geologic history is important. The known outcrops were described in a former publication and illustrated by means of a sketch map.† It is sufficient to add, perhaps, that they seem to be arranged along two axes. To the eastern one belong the granite at point Reyes and vicinity, that of the Santa Cruz and Gavilan ranges, and the small area near Cholame valley, in eastern Monterey county. To the

* Pacific Railroad Survey, vol. vii, p. 90.
† American Geologist, vol. xi, pp. 71, 72.

western axis belong the Santa Lucia range and the series of low outcrops extending diagonally across the upper Salinas valley to the San José range. The latter is the axis which appears to be the direct prolongation of the San Emidio and Peninsula ranges. The greatest width of the crystalline rocks of the Santa Lucia range is about 25 miles; of the Gavilan range, 12 miles. It is probable that the crystalline schists connect underneath many of the intervening valleys, filled with later formations, and all taken together form one original axis of upheaval.

Crystalline Schists and Limestone.—The crystalline schists are chiefly confined to the Santa Lucia range, where they are more extensively developed than the granite. In fact, they form the greater portion of that very rugged region, from a few miles south of Carmel bay to the San Antonio valley. The range rises very abruptly from the ocean, forming the grandest scenery to be found anywhere along the coast of California. The crest is formed of limestone for a number of miles. It is remarkable for the extreme degree of metamorphism which it has undergone. It is generally coarsely crystalline, and contains in many places a yellow mica, green pyroxene, molybdenite and graphite. The limestone occurs in an irregular lenticular form, the different outcrops varying from but a few feet to several thousand in thickness. It is found both in the granite and in the schists; in the latter case conformable to the stratification. Quartzites, hornblende and mica-schists appear, and undoubtedly represent sedimentary terranes, but by far the greater part of the rock is gneissoid. How much of this latter structure is due to a movement of a granitic magma while solidifying and how much to an original sedimentary stratification is not certain. On the western slope of the range there are large areas of a rock consisting of quartz, feldspar and chlorite which may represent an older granite. The line of steep mountains west of the Salinas valley, between the Arroyo Seco and Placitos creek, also belongs to the Santa Lucia axis. Gneiss, mica-schist and small areas of limestone occur here. The amount of massive granite is small, being most prominent about mount Toro. A small area of limestone outcrops in the San José granite range. Crystalline limestone appears in many places in the granite and gneiss of the Gavilan range. It is much purer than in the Santa Lucia, consisting almost wholly of calcium carbonate.

Granite.—In only one locality in the Coast ranges—that about Carmel bay, described by Dr Lawson*—has the granite been studied in detail. This granite is remarkable for the large crystals of orthoclase, with inclusions of the other components. A number of slides were prepared by the writer of specimens from different granite exposures through the central and southern Coast ranges. Distinctly porphyritic granite of the Carmel

* Bull. Dept. Geology, University of California, vol. i.

type has not been found to be very extensive. About San Lucia, the dominating peak of the Santa Lucia range, occurs a granite with much the same character, but not so coarse. In the San José range it is also to be found. This latter granite, as shown in the slide, consists of orthoclase, triclinic feldspar, quartz and mica. The large orthoclase feldspars contain inclusions of the triclinic feldspars and brown mica. Grains of titanite are scattered through the rock. Nearly all the sections made agree in the possession of the following components: orthoclase, triclinic feldspar in varying amount (in one specimen exceeding the orthoclase), quartz. brown mica, occasionally magnetite, apatite and titanite. Most of the specimens show glassy feldspars. Small dikes of a younger granite, quite similar to that described by Dr Lawson from Carmel, are numerous in portions of the San José and Gavilan ranges. All the specimens of granite examined are remarkable for the absence of hornblende. H. W. Turner* has made the following note on the granite of the Gavilan range:

"This granite is very different from that of the Sierra Nevada. It appears to be, indeed, a typical granite, and, as shown by a thin section, is composed of plagioclase, orthoclase, quartz and biotite, while the granite of the Sierra Nevada is usually hornblendic, with very little orthoclase."

The collection of granites which the writer has from the Klamath mountains shows, in general, quite a different character from that of the Coast ranges farther south. They resemble more the Sierra Nevada type. Specimens gathered from different portions of the Trinity mountains are coarse grained, with an excess of hornblende over biotite, and possess a large amount of triclinic feldspar, in some specimens in excess of the orthoclase. The granite of the eastern part of the Salmon range is similar. Between Redding and Shasta and in the Castle Crags region the granite has quite a different character and may possibly be older.

Evidence as to Age of the Basement Complex.—Nothing definite is known as to the age of the basement complex. Among the older geologists opinions as to the age of the granite ranged from "Primitive" to "Miocene." It has been shown by Dr Becker† to underlie the Cretaceous, and it was considered by him that the rocks of the Gavilan range were much older, possibly Primitive. Dr. Lawson‡ has shown conclusively that Whitney's view as to its being intrusive in the Miocene is wholly wrong.

In a former paper§ the writer advanced reasons for belief in the intrusion of the granite in the pre-Cretaceous series of uncrystalline rocks. A

* American Geologist, vol. xi, p. 324.
† Monograph on the Quicksilver Deposits of the Pacific Slope, p. 174.
‡ Bull. Dept. Geology, University of California, vol. i, p. 18.
§ American Geologist, vol. xi, p. 71.

further examination showed that this was not the case, and that the granite in this part of the Coast ranges probably does not correspond to the Mesozoic granite in the Sierra Nevada. H. W. Turner has supposed that the granite of the Coast ranges may be of Carboniferous age. While there is no evidence against this, there is no reason for assuming Carboniferous rather than a greater age. Recent investigations have shown that there are probably at least two periods of granite irruption in California. That of Mesozoic age is known to form the greater portion of the Sierra Nevada, while in the Coast and Peninsula ranges much of the granite is supposed to be older.

The sedimentary portion of the basement complex in the Coast ranges is characterized, in common with similar rocks in the Peninsula range, by an extreme degree of metamorphism. The past season large areas of limestone in the Santa Lucia were carefully examined, without discovering any traces of fossils. No outcrops were seen which were not so crystallized that it would seem impossible for fossils, if they ever existed, to have been preserved. No fossils of the Triassic or Jurassic have yet been detected in southern California, still those obtained by the writer from the Santa Ana mountains which were determined as Carboniferous may upon closer examination prove to belong to the Trias. It does not seem at all impossible that the crystalline schists and limestone of the main portion of the Peninsula range, as well as of the Coast range, are much older than the Carboniferous. The granite magma has been injected into these schists, and of course is younger. The presence of none but the most highly metamorphosed rocks in this series in the area under discussion would indicate a great amount of erosion, for which protracted intervals of elevation above the sea would be necessary. If this were not the case it would seem probable that in some portion of this crystalline axis less metamorphosed rocks should occur. Too little is yet known about the stratigraphic position of the slate, shale and limestone of the Santa Ana range to say whether or not they are to be correlated with the extremely metamorphosed schists. It is quite possible that there are granites of different age in this portion of the Peninsula range. As a result of our present knowledge it can be safely said that in that portion of the Coast ranges between point Reyes and San Emidio there is no evidence of Mesozoic granite, but that the whole basement complex is as old as the Carboniferous, and perhaps much older.

Relation of Basement Complex to oldest noncrystalline Rocks.—The relation of the basement complex to the oldest noncrystalline rocks, which the writer has termed the pre-Cretaceous for lack of better evidence as to their exact age, has been difficult of determination. The difficulty results

partly from the excessive development of the Tertiary, thus hiding the contacts, and partly from the almost universal tendency to the erosion of canyons along this line. The best region with which the writer is acquainted for observing the contact is on the coast of Monterey county, where the crystalline axis of the Santa Lucia leaves the shoreline at a small angle, and is gradually replaced southward by the pre-Cretaceous series without any break in the topography. Numerous deep canyons descend to the ocean, cutting across both the crystalline schists and the younger series, giving fairly good exposures. South of point Sur, for a distance of 25 miles along the coast, the belt of noncrystalline rocks, consisting of slate, sandstone and jasper, is quite narrow. In the vicinity of Slates Springs this series terminates downward by a coarse conglomerate nearly 1,000 feet thick and traceable for several miles. Slate forms the coastline at the springs. The strike is parallel to the coast; dip about vertical. It is followed by sandstone toward the mountains, and that by the thoroughly cemented conglomerate. The latter is formed of smoothly rounded granitic bowlders of all sizes, embedded in a sand of the same composition. The matrix is so hardened and metamorphosed as to closely simulate a crystalline mass. Most of the bowlders resemble the chlorite-granite which occurs along the western slope of the range. On the mountains north of Mill creek, and also on Vicente creek, the slightly metamorphosed sandstones of the pre-Cretaceous series were observed resting on the crystalline complex, with no intervening conglomerate.

The reason for the assertion that this noncrystalline series is older than the Cretaceous will be given later.

PRE-CRETACEOUS SERIES.

Character, Extent and Relations.—One of the most prominent features of the Coast Range geology is a series of rocks of rather peculiar lithologic character, concerning the exact age of which little is definitely known. It has undergone intense crushing over large areas, and exhibits more or less distinctly a silicious metamorphism, which as a rule makes its separation from the more recent formations easy. The series has been variously classed by different geologists as Tertiary, Cretaceous and metamorphic Cretaceous. The comparative uniformity of the rocks of this series from its most southern exposure to the Oregon line is a most remarkable feature.

The northern limit of the series along the coast never has been determined. The writer has been informed by Mr Watts, of the State Mining Bureau, that jasper and sandstone similar to that in the vicinity of San Francisco have been observed by him in Del Norte county along the

Oregon line, and it is probable that rocks of the same age are to be found in the Coast ranges of Oregon. The existence of a pre-Cretaceous series along the main crest of the Coast ranges in Tehama county has been amply proved. A similar series is exposed in all those portions of Humboldt and Mendocino counties not covered by the Tertiary. As we follow it southward it gradually becomes less prominent on the surface, being covered to a great extent by the Cretaceous and Tertiary. The farthest point to which it can be traced southward is southern Santa Barbara county, where it disappears beneath the Cretaceous. For a clearer idea of the distribution of these rocks in the Coast ranges the reader is referred to a map published in the American Geologist for February, 1893. It will be seen that south of Clear lake the exposed areas diminish very materially. Numerous small areas, which are not indicated on the map, are scattered through the Coast Range region, and it would seem probable that, with the exception of the granitic axes, it everywhere forms the basement on which the Cretaceous was laid down.

No attempt will be made to define its boundaries in the Klamath Mountain region, where rocks varying in age from the Jura-Trias to the Devonian are known to exist; nor is it known in what relation the pre-Cretaceous series of the central Coast ranges stands to the older rocks of Trinity and Shasta counties, but it is believed that much of it represents the last sediments deposited before the great upheaval terminating the Jurassic. The metamorphism gradually increases toward the north, where the rocks become fully crystalline.

Lithology of the noncrystalline Portion of the Series—Jasper or Phthanite.—The jaspers or phthanites, as they have been termed by Dr Becker, are the most characteristic rocks of the series. They are widely distributed, though their total area bears a small proportion to the whole. They form so striking a feature that they have been particularly referred to by all the earlier geologists. The beds consist of thin bands of silica, which under the miscroscope is shown to be a mixture of amorphous and crystalline silica in varying proportions, together with iron oxides and aluminous matter. The bands range in thickness from half an inch up to several inches, with thin partings of argillaceous matter. As a general thing the bands are more or less crumples and filled with minute interlacing quartz veins.

Blake* refers to these jaspers as much contorted and crumpled, ribbon-like and filled with veinlets of white quartz. He supposed that they had resulted from the metamorphism of sandstone and shale by igneous action.

* Pacific Railroad Survey, vol. v, p. 155.

J. S. Newberry * says of the jasper about San Francisco:

"Veins of white quartz, generally small, traverse it in every direction, and where it is weathered it is often peculiarly cellular, ragged and rough. Where stratified the laminæ which it exhibits are twisted and contorted in all possible directions, and, whatever is the history of the material of which it is composed, whether it is thrown up from below or, as is more probable, it is a metamorphosed form of the associated rocks, it is evident that it has been subject to a high degree of heat."

Whitney † refers to the jaspers as silicified shales.

They were first thoroughly studied by Dr Becker,‡ who speaks of them as "shales silicified to chert-like masses, of green, brown, red or black colors, intersected by innumerable veins of silica." He says further:

"Under the microscope the most highly indurated specimens are found to contain fossils."

All observers seem to have noted the wavy, thin bedded structure and the network of quartz veins. These characters are widespread, being exhibited by the jasperoid rocks of the pre-Cretaceous series through their whole extent in the Coast ranges. In the opinion of the writer, these peculiar jaspers are confined to that series and form one of the means by which it can be detected. The most striking outcrops with which the writer is familiar occur in Red Rock canyon, eastern Santa Barbara county, where an immense pinnacle of red jasper rises with precipitous faces 200 to 300 feet. At nearly every locality where the pre-Cretaceous series of rocks outcrops, from this point northward, the jasper is to be seen. Red jasper of a similar character has been observed in Trinity county and near the coast on the Oregon line.

A number of slides were prepared from specimens collected from different sections of the Coast ranges. A study of these showed the existence of such a remarkable uniformity that one description will answer for the essential features of them all. They consist of a minutely granular aggregate of crystalline quartz, with varying proportions of isotropic silica. The different colors are due to a varying amount of iron oxide, the red varieties being so impregnated with it as to be almost opaque. Minutely circular or elliptical areas, sometimes a millimeter in diameter, but generally less, are scattered through the rock, sometimes forming as much as a fifth of the total mass. By transmitted light these spots are distinguished by being clearer than the rest of the rock, while in polarized light they show a radial or granular aggregate of crystalline quartz which in optical properties resembles chalcedony. In only one slide was there noticed any traces of structure in these circular bodies.

* Pacific Railroad Survey, vol. vi, p. 12.
† General Geology of California, p. 66.
‡ Geology of Quicksilver Deposits of the Pacific Slope, p. 106.

There is no doubt that they all belonged originally to silicious organisms of the radiolarian type, but that in the various metamorphic actions to which the rocks have been subjected the structure has been nearly if not quite obliterated. This character was first noted by Dr Becker,* and on the authority of Professor Leidy was considered of organic origin. The silica which forms the mass of the rock belongs more to a chalcedonic variety than to quartz, for it seldom polarizes brightly. The minute intersecting veinlets are also partly of the same character; the larger ones, however, seem to consist of normal quartz.

The lessons to be drawn from these facts are that the jasper in its essential character is not a metamorphic rock, and that it was formed of silicious sediments resulting in great measure from organic life, as has been demonstrated to be the case with similar rocks in other parts of the world. In the Manual of Paleontology,† by Nicholson and Lydekker, the Radiolaria and the part played by them in the formation of silicious rocks is discussed. The following quotation will illustrate:

"Many of the Jurassic Radiolaria occur in jasper, flint or chert. Jaspers with Radiolaria are considered by Haeckel as of the nature of true 'silicified deep-sea Radiolarian ooze.'"

The entire freedom of the jaspers from any fragmental material deposited in the ordinary way near a shore would indicate their formation in deep or at least quiet waters. The very rare occurrence, however, of limestone in this series and the abundance of sandstone would seem to indicate the absence of deep-sea conditions during the deposition of the greater portion.

No one has yet worked out the stratigraphic position of the jasper beds in the series, and ascertained if they are distributed through it or confined to a single horizon. The wide occurrence of the jasper beds may not, perhaps, result so much from any great extent vertically as from the extremely crushed and broken condition of the series as a whole. As a result of this condition, strata of the same or nearly the same horizon might be exposed in many places. So far as the writer is aware, jaspery beds are absent from the recognized Cretaceous, but in the Miocene there again appear flinty beds of probably the same origin, but wholly free from the secondary silicification so characteristic of the earlier ones.

Sandstone.—Dr Becker has described the sandstones of this series, and nothing much that is new can be added. He emphasizes their arkose character and the evident derivation from granitic rocks, which he conceives underlie the greater part of the Coast ranges. The sandstone is by far the most extensive portion of the series. It presents a very uni-

*Quicksilver Deposits of the Pacific Slope, p. 108.
†Vol. i, pp. 147, 148.

form character, specimens from different portions of the Coast ranges differing more in degree of metamorphism than in any original character. Quartz is always present in more or less angular grains, but in all the sections examined it is excelled in quantity by the feldspar. The feldspar consists partly of twinned plagioclase and partly of orthoclase, the latter more abundant. Much of it, especially the smaller grains, is completely clouded. Hornblende was observed in only one specimen, that from Del Norte county. Mica is occasionally present in irregular brown scales, in part seeming to be of clastic origin and in part certainly as a secondary mineral developed in the metamorphism. Small quantities of iron oxide and other almost opaque minerals are present. The absence of hornblende from the sandstones of the central Coast ranges is strong evidence in support of the view of their having been derived from the preëxisting granite axis in that region, the rare occurrence of hornblende in the granite of the Coast ranges (excepting that of the Klamath mountains) being in such marked contrast to that of the Sierra Nevada. The prevailing color on a fresh surface is a dark gray; on weathering it turns yellowish. The somewhat angular form of the grains is a noticeable feature, one which bears out the view of the direct derivation of the components from the crystalline rocks without a great deal of attrition. The sandstones have been fractured and penetrated by silicious waters in a somewhat less degree than the jaspers. A massive, thick bedded character is to be noted in many places. These portions, though fractured, do not show the effects of crushing, as do the shales and thin bedded jaspers.

Shale and Slate.—Shale and slate form, next to sandstone, the most extensive portion of the series. Real slate, however, is not common on account of the peculiar conditions which have existed. There are but few areas of any extent where the pre-Cretaceous rocks appear in which there is not to be observed the effects of extreme dynamic action as a crushing force. These effects are particularly noticeable in the argillaceous portion. So far as observed, the main cleavage is parallel to the sedimentation. In areas where the pressure has been exerted normal to the plane of sedimentation a fine cleavable slate has been produced, but generally the strike and dip are so variable that a uniform direction of pressure would seldom be normal to the bedding. As a result, there are two or more intersecting lines of cleavage, so that the rock breaks up into sharply angular fragments. The action of numerous eruptive masses as well as faulting have also had a very important influence in destroying the regular cleavage. Where the distortion has been greatest the result is a clay, which has acted as a sort of cushion for the less yielding rocks. There are considerable areas of this series in the Coast ranges

where but little distortion and metamorphism have been felt, and the argillaceous rocks still retain their soft, shaly character.

The semicrystalline Portion of the Series.—As we follow the pre-Cretaceous series toward the north it gradually assumes a considerable degree of metamorphism, both chemical and dynamic. According to the reports of various observers, the series forms the basal rocks exposed in Mendocino, Humboldt and western Del Norte counties. The late W. A. Goodyear, for a number of years a member of the Geological Survey of California, under Whitney, though considering these rocks as metamorphosed Cretaceous, noted very distinctly the gradual increase of metamorphism toward the higher portions of the northern Coast ranges. In view of the utter lack of any attempt on his part to demonstrate a particular theory, the following quotation has the highest significance:*

"It appears to be a remarkable fact, which I noticed not simply on this Eel river trip, but also elsewhere in our travels, that as we approach the higher mountainous regions northwest of Clear lake the general lithological character of the rocks appears to undergo a gradual change. The country appears to be almost everywhere metamorphic, and, so far as I have seen, the degree of metamorphism is often higher than otherwise, though in some places every stage may be found from entirely unaltered to the most highly altered and crystalline rock, but the character of the change is different. The quantities of serpentine and of the jaspery and semi-jaspery rocks of the Coast range farther southeast rapidly diminish, while micaceous and hornblendic schists and argillaceous slates, etcetera, are oftener seen. In short, the rocks seem to belong to the classes which are generally more crystalline in their texture. The quantity of lime in the rocks also appears to diminish. White solid quartz occurs far more frequently. Even the granular metamorphic sandstones have a different look.

"At one point near Upper lake I noticed even the entirely unaltered sandstone so filled with scales of mica as to render its structure thoroughly schistose. Indeed, appearances everywhere are such as to suggest at once the question whether on going northwest from Clear lake, among the higher mountains, there is not a gradual and more or less complete change in the general lithologic character of the rocks, from that which is peculiar to the Coast range farther southeast to one which is more similar to that of the rocks on the western slope of the Sierra."

The writer's field-work has extended along the crest and eastern slope of the Coast ranges from Napa county north to Siskiyou county. The gradual increase in metamorphism is very plainly to be seen, together with a considerable change in the lithologic character of the rocks. Jasper, slate, hydromicaceous and chloritic schists occur in many places on the eastern slope of the Yallo Bally mountains, and, according to Mr Goodyear, the rocks on the western slope are much the same. The summit of the range consists of an exceedingly contorted and silicified

* Tenth Report of State Mineralogist of California, p. 316.

mica-schist, in places varying to green talcose slate, often semicrystalline. These schistose rocks are crumpled in fine lines and curves as if some mighty force had been exerted upon them parallel to the planes of stratification. On the eastern slope of the range the talcose or hydromicaceous schists were traced north to Bully Choop, in southwestern Shasta county. J. S. Diller, as well as the writer, obtained fossils from an outcrop of gray limestone near the base of the range in Tehama county. Mr. Diller has reported them to be Carboniferous. A limestone bed quite similar is reported as far south as Toms creek. The limestone and associated slates ought not to be confounded with the characteristic rocks of the pre-Cretaceous series, in which limestone is very rare. The rocks forming the summit of the Yallo Bally mountains to the west of the Carboniferous are undoubtedly younger—perhaps middle or lower Mesozoic. They are certainly not Cretaceous; J. S. Diller has given ample proof of this.

From Lake county northward the jasper, slate and sandstone become gradually more indurated, the sandstone turning to quartzite and the argillaceous rocks to mica and chloritic schists, the jasper being a silicious rock retaining much of its original character. The original lithologic character of the series undoubtedly gradually changes toward the higher portion of the Klamath mountains, and it is quite probable that the horizons represented in the middle Coast ranges do not appear there. As the disturbance and elevation in the Coast range axis culminated in the Klamath mountains, it is but natural to expect that successively younger strata would be exposed on the flanks.

ERUPTIVES.

General Characteristics.—The pre-Cretaceous series contains a great number and variety of crystalline masses intruded prior to the deposition of the Cretaceous. These are exclusive of the serpentine, which is considered to be of Cretaceous age.

The glaucophane-schists are among the most striking of those rocks which are supposed in part to have been derived from ancient eruptives. They have been noted by the writer from Santa Barbara county north to Lake county, and undoubtedly extend much farther. The glaucophane does not always form the chief constituent of these schists, but is associated with actinolite, hornblende, mica, chlorite, etcetera. Some geologists have considered these schists to be of sedimentary origin.* It is believed, however, that thorough study will prove that many of

*Since this was prepared for publication F. Leslie Ransome, Fellow in the University of California, has demonstrated that the glaucophane-schists of Angel island are the product of contact metamorphism.

these occurrences have resulted from the metamorphism of a crystalline rock. One strong argument in favor of its eruptive origin is the marked contrast between the small dike-like masses and the enclosing rock, which is often only slightly metamorphosed. In the San Onofre range, in San Diego county, is a breccia containing many fragments of glaucophane-schist, among which can be noted transitions to a massive crystalline rock.

Alteration an Obstacle to Identification.—The great numbers of intrusives in the pre-Cretaceous series, both dikes and surface flows, have been studied only in places. They are generally much decomposed, so much so that it is often difficult in the field to distinguish them from the sedimentary rocks. In many cases the original minerals have entirely disappeared, and their places have been taken by secondary ones. They have, of course, participated in the distortion to which the pre-Cretaceous series has been subjected. The most of them certainly antedate the Cretaceous.

ROCKS OF THE KLAMATH MOUNTAINS.

Characteristics and Relation to Rocks of other Localities.—All the evidence thus far gathered tends to show that no sharp lines can be drawn on lithologic grounds between the older rocks of the central Coast ranges and those ranges included under the term Klamath mountains. Stratigraphically those of the Klamath mountains are older. The silicious metamorphism of the central Coast ranges has been noted in many places in Trinity county and southern Siskiyou. There was also noted as accompanying it a disturbed and broken condition of the strata. These features were not prominent east of the north and south line of the Trinity mountains.

In a general way there might be two divisions made of the Klamath mountains—the eastern portion, in which the rocks resemble those of the Sierra Nevada and are comparatively regular in strike and dip, and the western, in which the rocks resemble those of the Coast ranges and have been mashed together rather than folded.

The Nonconformity beneath the Knoxville.—The nonconformity of the rocks of the Klamath mountains beneath the Shasta-Chico series is too well substantiated by the work of Mr Diller to need any further proofs. He says:*

"The same unconformity extends southwestward by way of Redding, Horsetown and Ono along the western side of the Sacramento valley into Tehama county, California."

That unconformity traced by Mr Diller, with all its marked features,

* Bull. Geol. Soc. Am., vol. iv, p. 221.

south to the fortieth parallel, the limit of his field, it is the object of the writer to demonstrate can be traced through the Coast ranges as far south as Santa Barbara county.

Orographic Movement.

ITS EXTENT AND TIME OF OCCURRENCE.

The upheaval which caused the deformation and metamorphism of the rocks of the Klamath mountains, there is good evidence to affirm, extended south as far as the rocks under discussion can be traced. The evidence adduced by Mr Goodyear of the gradual decrease of metamorphism southward should have great weight. His views, as expressed in the coloring of the preliminary geological map published by the California State Mining Bureau, show that he considered the rocks of the Yallo Bally mountains as more metamorphosed portions of the Cretaceous. In believing them to be Cretaceous he simply followed the prevailing views as to the "metamorphic series." In all his references to the slate, sandstone and jasper of the northern Coast ranges he conveys the idea that they all belong to one series. Time and again he also remarks upon the extreme deformation to which they have been subjected, as often shown by the complete obliteration of the stratification. This latter feature has been remarked by nearly all the workers in California geology.

PHYSICAL MANIFESTATIONS.

This remarkable convulsion had the effect of mashing the strata together and forming sharp folds. The character of the deformation is one of the most striking features of the pre-Cretaceous series as a whole, and is one of the many means by which it can very often be distinguished from the overlying Cretaceous. Although in the majority of cases the actual contact of the recognized Cretaceous with the older rocks cannot be found, yet the crushed and broken condition of the latter is in most marked contrast to the comparatively regular stratification of the Cretaceous, and is good proof of a physical break. The following quotation from Becker* is interesting as bearing on this point, and shows how different were the conditions of mountain-making at the time of this upheaval from those of any subsequent period:

"The metamorphic rocks have been dislocated in the most violent manner; indeed, the greater part of the mass was crushed at the time of the metamorphism to a small rubble. This is the case throughout the entire quicksilver belt, and renders it utterly impossible to plot any sections of the metamorphic strata."

*Quicksilver Deposits of the Pacific Slope, p. 293.

These conditions are undoubtedly due in large part to the lack of a fused upwelling magma along the line of weakness. Lateral compression must have been the chief cause of this pre-Cretaceous upheaval.

CORRELATION OF THE UPHEAVAL.

The recent work of the United States Geological Survey has demonstrated the Mesozoic age of the greater part of the granite of the Sierra Nevada. It seems to be the opinion of a number of paleontologists, among whom are Professor Hyatt and J. P. Smith, that the youngest of the sedimentary rocks involved in this upheaval belong to the Jurassic rather than to the Cretaceous, a fact for which the writer has contended on stratigraphic and lithologic grounds. This revolution in the Sierra region can be traced into the Klamath mountains, where the granite of the Trinity mountains is intrusive in slates, a part of which Mr Diller considers as belonging to the Jura-Trias. The effects of this stupendous revolution in the region of the Sierra Nevada and of the Klamath mountains, accompanied by the upwelling of a great granitic magma, must have been felt to a considerable distance. At the same time the pre-Cretaceous series of the Coast ranges experienced its first elevation from beneath the ocean. Toward the south the axes of uplift corresponded in part to the ancient granite ridges against which this series was deposited and in part were independent of them. Between the Trinity mountains and San Francisco bay the elevation and enormous erosion which has taken place since has brought to light no central axis. A series of ranges was formed with a trend slightly more to the west than the course of the elevation as a whole. All evidence at hand points to the fact of the first upheaval of the pre-Cretaceous series of the central and southern Coast ranges as being coeval with that of the Yallo Bally, Trinity and plexus of mountains to the northwest, which closed the Jurassic. In the Coast ranges proper there was no breaking and tilting back of the sedimentary series by a fused granite core. The movement was marked by a folding and crushing together of the strata to form a series of more or less parallel elevations.

METAMORPHISM INCIDENT TO THE MOVEMENT.

Dynamic Metamorphism.—During the period of elevation and deformation the dynamic metamorphism took place, being more intense toward the north. Through the Coast ranges south of the Klamath mountains this metamorphism was not great, though the rocks are referred to in geologic literature as "metamorphic." With local exceptions, they are uncrystalline, and only rarely have secondary minerals been formed.

Chemical Metamorphism.—Probably following the upheaval, and during

the time interval which intervened before the deposition of the lowest Cretaceous, occurred the peculiar chemical metamorphism which is apparent in rocks of this series wherever they outcrop. The silicious waters, the circulation and mineralization of which was due to the heat and chemical action existing during the mountain-making movements, permeated the rocks through the innumerable fissures which the strain had produced. This silicification was more pronounced in those strata sufficiently consolidated to be fractured; less so in the yielding argillaceous ones. As was shown in the sections of jasper, the numberless minute veins are largely formed of chalcedonic silica, and they were probably filled by infiltration from the jasper itself. The large veins in the jasper and all those in the other rocks have been filled from below in the manner described. With local exceptions, this silicification can be detected over the whole area occupied by this series from the most southerly outcrop to the northern boundary of the state. As the Cretaceous is free from this chemical metamorphism, even on the slopes of the Yallo Bally mountains, where it is the most pronounced in the older rocks, we have the strongest proof for its having taken place prior to the deposition of the Cretaceous. Moreover, this silicification of rocks known to be older than the Cretaceous in the Klamath mountains is traceable without any break, appearing only in less degree, through the whole extent of the Coast ranges. The lower Cretaceous, wherever it appears in the central and southern Coast ranges, is wholly free from any regional metamorphism, showing much the same character as on the eastern slope of the Yallo Bally mountains. Everywhere the deformation and metamorphism was strongly marked when the Cretaceous began to be deposited.

Correlation of the Quartz-veins.

It seems probable that the great quartz veins of the Sierra Nevada date from this same time; that is, posterior to the later granitic irruption. In the Sierra Nevada the regularity and size of the veins is due, in part at least, to the comparatively uniform strike and dip of the strata, while in the Coast ranges the extreme irregularity of the stratification made such quartz deposits impossible. Gold-bearing quartz-veins, small and irregular, are to be found from Santa Barbara county north to the rich gold-bearing areas of Shasta county. Small veins have been prospected for gold in the canyon of the Cuyama river, in northern Santa Barbara county. In Monterey county, in rocks of the same age, are located the deposits of the Cruikshank mining district. Here are rich but bunchy gold-bearing quartz-veins in crushed sandstone and shale. In many other portions of this county, as well as in San Luis Obispo

county, gold is found in quartz-veins in the pre-Cretaceous series. It has been found in small amount near San Francisco and at numerous other points through the central Coast ranges. Over a large part of the Coast ranges the chemical action resulting in the deposition of silica was less intense than in the Sierra Nevada, but there is no evidence which would place the formation of the quartz-veins of the two ranges at different epochs. With local exceptions, there is no evidence of any metamorphism, either chemical or dynamic, during any portion of Cretaceous or more recent times.

Age of the Sedimentary Series.

Paleontologic evidence.

The age of the series is a question concerning which there is very little evidence beyond the fact that it is pre-Cretaceous. The age of a portion at least, as indicated by the fossils which have been found, is not greater than the Jurassic. On the north it is not sharply defined from the Carboniferous and early Mesozoic. The past summer the writer found poorly preserved specimens of *Inoceramus* in the slates overlying the basal conglomerate before referred to as occurring on the coast of Monterey county. These fossils were examined by Mr Stanton and Professor Hyatt and pronounced not younger than the Cretaceous nor older than the Jurassic. It is very probable that the *Inoceramus* reported by Professor Whitney from Alcatraz island, although better preserved, is fully as indefinite in its time indication. The rocks of that island are not separable lithologically from the pre-Cretaceous series north and south.

That less than a half dozen poorly preserved specimens should have been discovered up to the present time, notwithstanding all the search that has been made, is a very remarkable fact. Over much of the region the metamorphism has not been sufficient to destroy the remains of life if it ever existed, but it would seem probable that the extreme deformation to which a large part of the area has been subjected is one of the chief causes of the obliteration of fossils. The species found are rather indeterminate in character, and while paleontologists may differ as to whether they indicate Jurassic or Cretaceous age, stratigraphic and lithologic considerations place the strata containing them in the Jurassic.

It seems to be quite certain that wherever the Lower Cretaceous occurs it has been found to be well supplied with the remains of molluscan life. On the other hand, that very series of rocks which on lithologic and stratigraphic considerations the writer would refer to an earlier age have so far proved almost barren of life. It would be strange if this far-reaching condition should not have an important significance. It is

becoming more apparent every day that the determinations of the age of strata based merely on a scanty fauna are in many cases very uncertain.

STRATIGRAPHIC AND LITHOLOGIC EVIDENCE.

Although it is a general principle laid down in geology that correlations based on stratigraphy and lithology in regions in which the strata cannot be traced by continuous outcrop are to be accepted with caution, yet the writer believes that in a study of the Coast ranges, where fossils are rare in the older rocks, these determinations, properly used, are of the highest importance. The fact that rocks of this series are marked everywhere by constant lithologic features and exhibit the same kind of metamorphism as the rocks of the Klamath mountains is sufficient to enable us to separate them from the Cretaceous. The metamorphism, though not always pronounced, is distinct enough, when taken in connection with the lithologic features, to enable the lines to be drawn. The validity of this demonstration of course rests upon the fact of the absence of metamorphism, both dynamic and chemical, from all portions of the known Cretaceous. The writer has examined portions of nearly all the areas of Cretaceous in the central and southern Coast ranges, but has never yet encountered any jasperoid rocks in that formation.

The rocks of the pre-Cretaceous series generally show a character peculiar to the Coast ranges, yet in places portions of the series resemble the metamorphic rocks of the Sierra Nevada. In the northern counties there are many outcrops of a finely cleavable slate. In Monterey county a large area of slates extends southeast from Salmon creek for several miles. The slates are black, cleave as finely as those along the Mother lode in the gold belt and in manner of decay very closely resemble them. The extraordinary development of sandstone and jasper are perhaps the striking lithologic features. The abundance of sandstone would indicate shallow waters not far removed from land areas. It seems quite probable that the basement complex of crystalline schists and granite stretching from point Reyes to the Peninsula range was in early Mesozoic times far more elevated than at present. Toward the middle Mesozoic a sinking began, continuing through the Jurassic, but insufficient to cover the granite ridge on the flanks of which the pre-Cretaceous rocks were laid down. This ancient granite range now appears, where not elevated by recent movements, as a sunken range or one worn down to baselevel.

The almost entire absence of limestone in the pre-Cretaceous series is a remarkable fact. It is one of the evidences of shallow water near to land areas. As we go north into the Klamath mountain region in Trinity and Shasta counties the limestone becomes abundant. In that region there is a less predominance of sandstone. These facts all point

to the existence of an extensive land area in the region of the central Coast ranges during early Mesozoic times, one which perhaps extended as far west as the Farralone islands, which consist of granite and belong to the continental plateau. To the southeast it was likely continuous with the Peninsula range of Southern California.

Cretaceous of the Coast Ranges.

DISTRIBUTION.

The Cretaceous is widely distributed in the Coast ranges. It occurs on the eastern slope nearly the whole length of the San Joaquin and Sacramento valleys. Within the Coast ranges it occurs more extensively south than north of San Francisco. The past season the writer discovered that a large portion of the high mountains in northern Ventura and Santa Barbara counties consists of Cretaceous and Eocene strata, showing in places an enormous thickness, comparable to that found by Mr Diller in Tehama county. As far as the scanty paleontologic evidence goes, the greater part of this series appears to belong to the Upper Cretaceous, extending upward into the Téjon or Eocene, with a comparatively small development of distinctly Lower Cretaceous. In northern Ventura county there is an exposed width across the strike of the Chico-Téjon series of twelve miles, but the dip is so irregular that the thickness could not be determined. In Santa Barbara canyon, which cuts somewhat diagonally across the stike of the rocks of the same series, they show an almost uniform dip for a distance of ten miles. The dip is to the southwest at an angle of about forty-five degrees, and the estimated thickness at least twenty-five thousand feet. In San Luis Obispo county the Chico, the Téjon not having yet been recognized, consists largely of sandstone, and is confined to the line of the Santa Lucia mountains, occurring along the eastern slope at least as far north as central Monterey county. The Chico-Téjon is also found in San Benito county on the western side of the Monte Diablo range. On the eastern side of the range in Walton canyon there is an exposed thickness of at least twenty thousand feet. The Chico is known to occur on the coast north of San Francisco and in some of the interior valleys.

H. W. Turner several years ago detected the Lower Cretaceous in the Santa Lucia range near the town of San Luis Obispo. The writer has traced the black shale of this formation along the summit of the range for some miles. Numerous specimens of *Aucella* were found in it near the Old Padre mine west of Santa Margarita; also on Toro creek and at an intervening locality, and on Pine mountain near San Simeon. This formation, consisting almost wholly of black shale, begins a little southeast of the new railroad tunnel, and extending along the eastern side of

the range for several miles, crosses it on the head of Morro creek, and on Toro creek appears enclosed between two high serpentine ridges which form the crests of the range. It was found again on Pine mountain on the summit of the range back of San Simeon. Here it is capped by a body of liparite. Outcrops of somewhat limited extent of supposed Lower Cretaceous shales were seen a few miles west of Santa Ynez, in Red Rock canyon, and Cachuma canyon, Santa Barbara county.

SEPARATION FROM THE PRE-CRETACEOUS BY AN UNCONFORMITY.

The unconformity of the Lower Cretaceous on the older rocks of the southern Coast ranges is evident, though no good contacts were observed. Excellent contacts of the Upper Cretaceous with the pre-Cretaceous were seen in a number of places and will be described later. The small area of *Aucella*-bearing Cretaceous on the summit of Pine mountain overlies rocks of the pre-Cretaceous series. The Cretaceous consists of shale with some thin strata of sandstone dipping irregularly into the mountain. As the mountain is descended this is seen to be replaced by crushed and distorted rocks of the older series, consisting of shale, sandstone and jasper, with an apparently vertical dip. The area of *Aucella*-bearing rocks farther south was inclosed in serpentine in such a manner that the contact with the older rocks was not seen. The sharp contrast, however, between these soft shales and sandstone, with comparatively regular strike and dip, and the older distorted series is very marked. Areas of undoubtedly Lower Cretaceous age occur in Cachuma canyon and Red Rock canyon in such relation to the underlying series that there can be not the slightest doubt as to an unconformity.

ABSENCE OF REGIONAL METAMORPHISM.

There is an entire lack of regional metamorphism in all the known Cretaceous of the state. As far as the amount of consolidation and hardening is concerned, both upper and lower divisions present much the same character in the southern Coast ranges as in Tehama and Shasta counties. There is an absence also of the great crushing exhibited by the older rocks. Although in some places much disturbed and folded, the stratification is generally very distinct. The regularity of the bedding of the Upper Cretaceous, when found resting on the pre-Cretaceous series, is in very marked contrast to the irregular, wavy and often almost indistinguishable bedding of the latter.

LITHOLOGIC CHARACTER.

The lithologic character of the Lower Cretaceous in the southern Coast ranges is much the same as farther north. There is the same excess of soft, dark shales, with thin strata of sandstone and calcareous nodules

The Chico-Téjon consists to a great extent of coarse sandstone, with a lesser amount of shale and conglomerate.

RELATION OF THE CHICO TO LOWER CRETACEOUS AND PRE-CRETACEOUS.

North of the fortieth parallel Mr Diller has found no break, physical or paleontologic, in the whole series of Cretaceous sediments. While he finds the lower portion of the series somewhat more crumpled, no unconformity appears to exist. Whether we accept fully his conclusions or reject them for other portions of the Coast ranges, it is very evident that there were no great disturbances of a character to metamorphose the lower portion. As to the hardening and solidification, there is very little difference between the extremes of the series. The work of the writer in the Coast ranges has led him to believe that approximately similar conditions existed during the deposition of the Cretaceous the whole length of the state; that there was a physical break, which is more or less prominent in different localities.

Along the trail from the Cachuma canyon across the San Rafael mountains to the head of the Manzana a very thick section of the Cretaceous is exposed. These beds rest at a steep angle against serpentine, jasper, sandstone and shale of the older series. The base of the Cretaceous is a black shale filled with calcareous nodules. As exposed in a canyon leading down to the Manzana the Cretaceous dips to the north at an average angle of 45°, having a thickness of 8,000 or 10,000 feet. An ammonite was found here, but in such a poor state of preservation that the species could not be determined. At a distance of three miles down the canyon the shales and sandstones are replaced by very extensive conglomerates, with an apparent dip of 30°. The conglomerate is several thousand feet thick. It is quite probable from what was observed in the northern part of the county that this conglomerate is a part of the Chico-Téjon. It would seem highly probable that future investigations will prove the existence of the Lower Cretaceous in this region. The present evidence favors the view of a break in the series. In the southern Coast ranges the direct superposition of the Upper on the Lower Cretaceous has not been observed, either one or the other of the divisions being absent.

In the canyon of the Cuyamas the unconformity between the Cretaceous, probably the upper division, and the pre-Cretaceous series is most plainly shown. The deepest portion of the canyon is cut through a series of crushed sandstones and shales, containing small quartz-veins, jasper and dark green, fine grained eruptives. On this series the Cretaceous shale and sandstone was seen, resting at an angle of about 40°, wholly unaltered and with regular bedding lines. Now, since the rocks which have been referred to the pre-Cretaceous series have been found nearly continuous from the Klamath mountains south to this point, maintain-

ing very much the same lithologic character, and inasmuch as the lowest Cretaceous, when it occurs, also rests unconformably on the same series, we have the strongest evidence that this unconformity, so unequivocally shown, is the same which has been found to exist in the northern part of California. If it is not, then there must exist a comparatively local disturbance and metamorphism within the Cretaceous exactly simulating that at the base of the Cretaceous farther north, but the character of the lowest Cretaceous found in several localities in this region utterly forbids this supposition. Let it be understood, however, that this does not disprove a disturbance merely, during the Cretaceous, which the writer holds is demonstrable.

PROBABLE EPOCH OF THE SERPENTINE INTRUSION AND ITS EFFECT UPON THE CRETACEOUS.

Mr Diller, in a recent publication,* says, with reference to the serpentine, that it is undoubtedly an altered eruptive and younger than the Knoxville portion of the Shasta-Chico series. With this view the writer is in complete accord. Instances of contact metamorphism were given in a former paper. There are no recorded observations of the serpentine having been found eruptive in the Chico. About Clear lake is a large area of sandstone of this age, and while serpentine occurs in the older rocks near by, none is present in the Chico. It will, perhaps, be argued that the Chico is generally found farther away from the axis of disturbance than the Knoxville, which is the case along the west side of the Sacramento valley; but in several places farther south the Chico was observed superimposed on the serpentine, and nowhere was it seen intruded by that eruptive. The Chico rests on serpentine in many places in the Santa Lucia range, while in other localities, particularly in the canyon of the Santa Ynez river, the serpentine is intruded in black shales of Lower Cretaceous age. Over that great extent of country in Ventura, Santa Barbara, and San Luis Obispo counties covered by the Chico-Téjon there are no traces of serpentine, while in nearly every spot where the pre-Cretaceous or Lower Cretaceous is exposed by erosion dikes of serpentine are found. This was noted in the mountains east and north of Santa Ynez, in the Santa Lucia range south of Poso, and at other points farther north.

At some period during the Cretaceous a disturbance took place, probably an elevation, extending through the whole length of the Coast ranges, and accompanied by the extrusion of peridotitic eruptives. Although in some cases the areas of these eruptives are very large, yet the metamorphism shown by the enclosing rocks is not usually very pronounced, while the tilting and fracturing of the strata did not extend far.

* Bull. Geol. Soc. Am., vol. 5, p. 441.

In places the disturbance could not have been felt to any extent, as in Tehama county, where the relations of the Shasta-Chico series have been studied so carefully by Mr Diller. In that region along the west side of the Sacramento valley where the Cretaceous is so enormously thick the Chico is found several miles from the line of intrusion of the serpentine in the Lower Cretaceous and older rocks, and the disturbance is not noticeable at that distance. Mr Diller even remarks the greater amount of disturbance exhibited by the Knoxville and the lack of it in the Chico, but accounts for it by the fact that the Upper Cretaceous does not at present appear superimposed on the Lower, but at a considerable distance, where the axial movements were not felt.* An upheaval accompanying the serpentine might account for the greater amount of sandstone in the Chico, especially toward the south.

Tertiary of the Coast Ranges.

Eocene.

So little is yet known of the detailed geology of much of the southern Coast ranges that the relation of the Eocene to the Chico cannot be stated with certainty. Fossils from both upper and lower divisions of the series have been found in different portions of Ventura and Santa Barbara counties in an apparently conformable series of rocks, but there is no blending of the faunas. The extent and character of the series has been already described.

Miocene.

The most extensive of all the formations in the southern Coast region is the Miocene. Not only does it form the greater portion of the valleys, but in many instances isolated patches are found capping some of the highest ranges. At the close of the Miocene and before denudation began, strata of this age formed an almost universal covering, gradually decreasing in importance toward the north. It is this fact which led the earlier geologists to claim a Miocene age for the Coast ranges. It seems probable that after the beginning of the Miocene and as deposition went on a subsidence took place, for the basal portion wherever exposed shows a loose granitic sand rock, characterized in many places by the gigantic oyster, *Ostrea titan*.

The nonconformity of the Miocene on the Chico-Téjon is one of the most striking facts to be observed, notwithstanding the existence in geologic literature of many references to the conformity of these two formations. The unconformity was noted in the high ranges in northern

* Bull. Geol. Soc. Am., vol 4, p. 222.

Ventura county along the Sespe, in the valley of the Sisquoc, canyon of the Cuyamas river, south of the old mission of Santa Ynez, in the upper valley of the Salinas, and many other places. The nonconformity is so pronounced that it is surprising it should have escaped the observations of the older geologists. Dr Lawson has recently called attention to a nonconformity between the Miocene and the supposed Téjon at Carmel bay.

The Santa Ynez is the greatest single range formed wholly of Miocene strata. Lithologically, the Miocene is strongly marked, the bituminous slate series of Whitney being the most widespread and characteristic portion of the formation. These rocks have been studied recently by Dr Lawson, with the development of some interesting features. Gypsum-bearing clays are also very widely distributed.

A great elevation of the Coast ranges took place at the close of the Miocene, a fact noted by all geologists. There is no portion of the state where this has been so great as in the San Emidio range, where the Tertiary is found flanking mounts Frazer and Pinos at elevations varying from 5,000 to nearly 7,000 feet. Rocks of Miocene age cap the summit of the Monte Diablo range, in southwestern Fresno county, at an elevation of 4,000 feet. In various places in Santa Barbara county the Miocene has an elevation of from 3,000 to 4,000 feet.

Formation of new Axes with each succeeding Elevation.

A feature of peculiar interest in this region is the fact that the Coast ranges do not consist of one main axis with a dominating range, but of a number of wholly independent ranges formed at different geologic periods. The northern portion of the Santa Lucia range, and the almost buried granite ridge connecting it with the San José range, belongs to one of the two or three earliest elevations in this region. At the pre-Cretaceous upheaval a divergent range was formed which constitutes the southern continuation of the rugged granite ranges of Monterey county. Additional movements took place along this line, while the granite ridge extending a little more easterly remained comparatively undisturbed. The Santa Ynez range seems not to have existed until post-Miocene times.

A little south of Santa Margarita, along a line from the valley to the summit of the Santa Lucia, there is crossed successively the pre-Cretaceous, the Cretaceous and the Miocene. The presence of the older rocks in the valleys or on the slopes of the range and the younger on the summit is a condition very striking in many places. Over much of what might be termed the Coast Range plateau the compressive and elevating

forces did not always act upon the already existing axes, but new ones were formed by their sides or even in divergent directions.

The Coast Ranges Constitute a Mountain System.

Professor J. Le Conte gives the following definition of a mountain system:

"A mountain range is a single *mountain individual*, born at one time (monogenetic)—*i. e.*, the result of one, though it may be a prolonged, earth effort—as contradistinguished on the one hand from a mountain *system*, which is a family of mountain ranges born at different times (polygenetic) in the same general region, and on the other from ridges and peaks, which are subordinate parts, limbs and organs, of such a mountain individual."

It seems to the writer that this definition is applicable to the Coast ranges; that they should properly be considered a system of mountains, embracing, as they do, ranges of such different ages. This is particularly applicable to the region south of San Francisco bay. On the north there is not shown such a complexity of structure.

If the writer's views are correct, the Coast ranges are not younger than the Sierras, as has been generally supposed. According to our present information, land areas existed in this region before the Jurassic upheaval, which, in the opinion of Dr Le Conte, gave rise to the main portion of the Sierra Nevada.

Sketch of the Geologic History of the Coast Ranges.

The age of the crystalline schists and limestone of the Coast ranges is unknown. At some period, probably during the Paleozoic or possibly earlier, an upheaval accompanied by the formation of granite took place along the axis of the Coast and Peninsula ranges, intensely metamorphosing the sedimentary strata. Owing to the fact that no trace of uncrystalline rocks older than the Jurassic has been detected along this axis, it seems justifiable to suppose that during the early Mesozoic, and perhaps later Paleozoic, the land area of the crystalline rocks was far more elevated and extensive than at present. Erosion through long intervals of geologic time would be necessary to remove all traces of the less crystalline upper rocks of this complex.

If authorities are correct, a broad sea stretched to the east over the most of the Sierra region during the period of erosion of this crystalline axis of the Coast ranges. As Mesozoic time progressed a subsidence began and continued through the Jurassic, with the deposition of what has been termed the pre-Cretaceous series. At the close of this period the great revolution in the Sierra Nevada took place, accompanied by a tilting and folding back of the strata and the formation of an enormous area of a fused granite magma. At the same time an axis of uplift was formed in the Coast ranges, being connected with the Sierra Nevada at

both ends. The elevation was accompanied by no fused central mass, but appears to have been due to a horizontal compression, resulting in a mashing together of the strata. The granite axis experienced a renewed uplift, while that portion of the Coast ranges between point Reyes and the Klamath mountains first emerged from beneath the ocean. This theory correlates in time the youngest sedimentary strata of the gold belt with the pre-Cretaceous uncrystalline series of the Coast ranges. Following the upheaval, the silicification of both ranges took place. A considerable interval of erosion is believed to have elapsed after the former event before the deposition of the lowest Cretaceous yet discovered. A subsidence continued through the Cretaceous and Eocene, except for a break, not everywhere apparent, at the time of the intrusion of the peridotitic eruptives. At the close of the Eocene another elevation took place, followed again by a depression through the Miocene, so that the latter was laid down unconformably on the Chico-Téjon. At the close of the Miocene another great elevation of the Coast Range region was experienced. Strata of that age have at present an elevation of nearly 7,000 feet in northern Ventura county. Following this other disturbances have been recorded, but will not be touched upon here.

Conclusions.

The discussion in the previous pages, it is hoped, has demonstrated the existence of a series of uncrystalline rocks in the Coast ranges of greater age than the Cretaceous. This series underlies the Cretaceous unconformably, and rests on the worn surface of the crystalline basement complex. It is marked by peculiar and constant lithologic features, and has undergone to a greater or less degree a silicious metamorphism, distinctly marking it from the younger formations.

Attention is called to the following points, which, though less dwelt upon than the main topic, are yet of great importance:

1. The seemingly great age of the crystalline basement complex; a view which, if correct, gives the Coast ranges an antiquity greater than that of a large part of the Sierra Nevada.

2. The undoubted radiolarian origin of the jaspers of the pre-Cretaceous series, and consequently the incorrectness of applying the term "metamorphic" to them.

3. The probable nonconformity between the Upper and Lower Cretaceous.

4. The nonconformity between the Miocene and Chico-Téjon series.

5. The great diversity in age and complex structure of different portions of that continuous series of mountains known as the Coast ranges, making them worthy of being considered a mountain system.

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ON

ANALCITE DIABASE

FROM

San Luis Obispo Co., California

BY

HAROLD W. FAIRBANKS

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FIELD RELATIONS.

SAN LUIS OBISPO COUNTY is situated in the Coast Ranges of California, nearly midway between San Francisco and the southern boundary of the State. The topography is characterized by a series of mountain ranges extending northwest and southeast, constituting the Coast Range system. The geology of this region is

*These interesting rocks were discovered by the writer while engaged in field work for the State Mining Bureau. Their petrographic investigation was conducted in the geological laboratory of the University of California.

complex, but as yet it has been studied very little. In addition to the Tertiary and Cretaceous there is a pre-Cretaceous uncrystalline series and a basement complex of crystalline rocks. Many bodies of eruptives of various ages, and exhibiting a wide range in chemical composition, are found in different portions of the area.

One of the eruptive masses to be described lies in the extreme southeastern part of the county, in the range of desert mountains between the Carisa Plain and the Cuyamas Valley. The second is found on the western slope of the Santa Lucia Range, about seventy-five miles distant in a northwest direction. The third and least important occurs on the Eagle Ranch, in the Santa Lucia Range, about six miles west of the town of Santa Margarita.

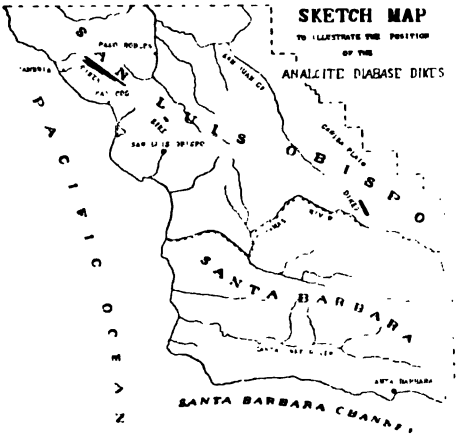

Figure 1. Index Map.

The range in which the Cuyamas dike occurs is the watershed between the San Joaquin Valley and the Pacific Ocean, having an elevation of nearly 4,000 feet in places. Topographically it forms the connecting link between two granite ranges, the San Jose on the northwest and the San Emedio on the southeast. It rises quite abruptly from the broad and desert valley of the Cuyamas, presenting a most barren and forbidding aspect. Owing to the absence of vegetation, the general geological structure is easily made out. Although no fossils have been found in this range, yet the general nature of the formation and its relation to the known Chico-Tejon lying on the northwest and west, indicate that it is of Miocene age. The strata are but slightly consolidated, those of an argillaceous nature predominating. The eruptive body, as far as is known, lies wholly on the western side of the range. It begins nearly opposite the Spanish Ranch, about two miles from the valley, where

it has a width of about 1,000 feet, and extends in a northwest direction for a number of miles, gradually becoming narrower. The southern portion, exhibiting by far the greatest variation, and possessed of the most interest, is that from which the material for study was collected.

The second occurrence, which will be described in this paper, has a length of about twelve miles, extending northwest and southeast parallel to the Santa Lucia Range, on the slope of which it lies. The most southerly portion examined is exposed in a cut on the road from Templeton to Cayucos. The next point at which it was observed is at the foot of the grade on the road from Paso Robles to Cambria. At both these localities the sections are not good, and the rock is exceedingly friable and decomposed. Two miles northwest of the last locality, near the old Oceanic quicksilver mine, a deep cañon has been eroded across the eruptive body, giving an excellent section. At the southern exposure only one dike was noted. At the middle there are three, while in the cañon at the Oceanic mine there are four, the largest being nearly 300 feet wide. The dikes, as in the case of the Cuyamas occurrence, are inclosed in rocks of probable Miocene age.

CONTACT METAMORPHISM.

This phenomenon is very noticeable in the contact rocks of each of the occurrences. In that of the Cuyamas the strata have been tilted up vertically on each side of the dike, and distinctly changed for a distance of 100 feet. In an old tunnel, run in prospecting for silver, it is well shown; also in a cañon cutting across the dike farther north. At the latter locality a large mass of the country rock appears on the north wall of the cañon wholly inclosed in the eruptive.

Macroscopically the metamorphism appears to consist of an induration and blackening of the soft gray clays and calcareous sandstones, the clays having been changed to a black shining slate, and the incoherent sandstones to hard, slaty masses, giving a ringing sound when struck. The dark color is probably due to the effect of heat on the organic matter contained.

The nature of the inclosing rocks and the metamorphism

induced is very similar in the series of dikes near the Oceanic mine. Microscopically but little of interest appears in any of the slides prepared from the metamorphosed contact rocks. Mica, in the form of minute scales, seems to be the most important secondary mineral which can with certainty be made out. A recrystallization of the calcite has taken place in the sandstone forming individuals inclosing the other components, as shown by the luster on fresh surfaces of the rock.

MACROSCOPICAL CHARACTER OF THE CUYAMAS OCCURRENCE.

This eruptive mass consists of two distinct portions: (1) The main one, which is dark and fine grained; (2) ramifying dikes of later origin, much harder and lighter colored. The main body has the appearance of being very greatly decomposed. It is with difficulty, even in the deepest cañons, that hand specimens can be obtained which will not crumble upon a slight pressure. The mass is entirely free from any schistose tendency, but in places inclines to a shelly spheroidal structure. Such is the ease with which the rock disintegrates that the contour of the hills which it forms is not noticeably different from that of the unconsolidated Tertiary strata of a large part of the range.

The dikes which intersect the main body form the most interesting feature of the whole occurrence. They have a somewhat similar composition, but are generally much fresher. They cut the main dike in all directions, and are in most cases rather narrow, ranging from about six inches to two feet in width. They are more numerous near the western edge of the main mass, where there are several ten to eighteen feet wide. The most of these are hard and project above the crumbling rock inclosing them. As the latter weathers away, the dikes break up into masses of varying size and roll into the cañons. Occasionally one of these dikes is almost as dark and decomposed as the inclosing mass, but generally they are in sharp contrast with the latter. The very narrow ones are finer grained than the inclosing rock, but the broad ones are considerably coarser. All possess a granular structure which is as pronounced in the narrow ones as in the broad ones. It is probable that after the cooling of the upper portion of the main mass a strain

again occurred forcing up the still unconsolidated portions of the magma through fissures. That part already consolidated may have been warm, and so have permitted of a slow cooling of the secondary dikes, thus enabling them to take on a granular structure. The mineralogical composition of these dikes, compared with that of the main body, would suggest that either the conditions of cooling were different, or that there was a slight variation in chemical composition of the magma.

In a cañon which cuts across the main body about half a mile from its southern end, one of the largest of the secondary dikes is well exposed. The surface has been blasted off in search for silver, and good specimens for study were obtained. Near the edge of the dike there are irregular cavities, some of them two centimeters in diameter, partly filled with calcite and analcite. The analcite is also disseminated through the body of the rock in water clear grains, some six millimeters in diameter. They break with a splintery fracture and are frequently iridescent. In many cases this mineral is undergoing a change to a radial fibrous aggregate, determined by blowpipe tests to be natrolite. In some of the dikes the latter has almost entirely replaced the analcite. As a rule the feldspar and pyroxene show no striking peculiarities, although the former has a dull luster indicating decomposition. In the large dike, from which the most of the material was collected, the pyroxene is present in crystals which are sometimes fifteen millimeters long, and show a pronounced lamellar cleavage. These crystals are lustrous black on the outside, but within, a large proportion of them exhibit on part of the cleavage faces a bright silvery luster. The shining appearance is associated with the formation of a transversely fibrous structure. The boundary of this area is sharply defined from the black, lustrous outer portion of the crystal by a straight line of contact parallel to the long diameter of the crystal. What seem to be minute irregular fissures appear in the centers of these cleavage faces and extend the length of the crystals. While the silvery portion has an apparently fibrous structure, this is not exhibited when the crystal is split; but, instead, there is a strong tendency to the formation of thin, almost micaceous plates parallel to the diallagic cleavage.

MICROSCOPICAL PETROGRAPHY OF THE MAIN DIKE.

Owing to the exceedingly friable nature of the dark rock of the main body, only one section was prepared from it. Under the microscope this is seen to possess a holocrystalline diabase granular structure. The components, given in order of their separation, are: magnetite, olivine, feldspar, augite, and, last of all, the constituent which probably once occupied the angular areas, now filled by analcite, between the older constituents.

The feldspar is present in short lath-shaped and tabular forms, twinned according to the albite law. Twinning is seen in all except some tabular ones which show a decided zonal structure, the angle of extinction decreasing from the center outward. Many of the crystals are dotted with sharply defined isotropic areas. These, on farther investigation, proved to be analcite, and will be more particularly described in connection with the secondary dikes. The feldspars are also being invaded by a green to brown fibrous or granular material. This substance is particularly prominent in the angular spaces between the feldspars from which it has spread. Owing to the state of decomposition of the feldspars but few extinction angles were observed, and they were not generally symmetrical to the twinning plane; but it would seem from the fact that several were between twenty-five and thirty degrees that the feldspar must be fully as basic as labradorite.

Augite appears in allotriomorphic form, showing only slight signs of decay. It occurs either in large masses penetrated by and inclosing the feldspars, or in wedge-shaped areas between them. It is distributed quite irregularly over the slide. The color is a pale brownish green, no pleochroism being noticeable. Interpositions of dark dust-like particles appear along irregular planes, and are possibly of secondary origin. It is distinguished from the orthorhombic pyroxene by the high extinction angle on $\infty P\bar{\infty}$.

A reddish brown almost opaque substance is present in considerable abundance, occupying fully as much of the surface of the slide as the augite. In places it is not sharply differentiated from the matty green material, but in general has quite well-defined boundaries, which in several cases are hexagonal. In some of these

areas appear parallel partings, but the most have no structure and are surrounded by a dark opaque border of thickly aggregated magnetite particles. It would seem that there can be no doubt that these products indicate the original presence of olivine.

Magnetite is quite abundant as a primary constituent in the form of grains and long, slender rods. A chemical test showed the presence of titanium, while its magnetic properties distinguish it from ilmenite.

Analcite was evidently once quite abundant in the rock, filling wedge-shaped areas between the feldspars and augite. It has largely been replaced by the brown and green fibrous aggregates, whose exact nature is indeterminable. The larger areas still show in their centers an isotropic substance, which agrees in every particular with that proved to be analcite in the fresher dikes. The manner of occurrence of the analcite, as well as the structure of the rock, is shown in Plate 15, Fig. 1.

MICROSCOPICAL PETROGRAPHY OF THE SECONDARY DIKES.

Many sections were prepared from the large secondary dike which had been opened by prospectors. This is by far the freshest as well as most interesting of the secondary intrusions. The structure of the rock, as seen in thin section, is holocrystalline, approximately panidiomorphic. This dike, in common with all the secondary ones, contains no primary olivine; and the augite, instead of following the feldspar in order of crystallization, has either crystallized simultaneously or preceded it. In the latter case it exhibits large idiomorphic crystals.

Plagioclase.—The feldspar is present in the thin sections in short lath-shaped and tabular forms. The characteristic twinning is that according to the albite law, but in some instances it is found in combination with the pericline law. All the individuals show polysynthetic twinning in both broad and narrow plates, except the broad tabular forms, which are evidently cut parallel to $\infty P\bar{\infty}$, the composition plane, as they show the emergence of a bisectrix without the field of the microscope. The tabular forms exhibit a remarkable zonal structure. Many individuals were observed with a difference of 10°, and several as much as 18°, in the angle of

extinction between the inner and outer portions, the angle decreasing from the center outward. Twinned sections have a less marked zonal structure or none at all; a fact which might be explained by the more rapid growth of the crystal in $\infty P\bar{\infty}$ (010) than in the direction normal to that plane. There are scarcely any individuals but which are more or less decomposed, so that the correct determination of the extinction angles is difficult. The attempt to obtain cleavage plates which should show twinning was not successful, and the classification had to be based on sections cut haphazard. Taking all the sections together, about thirty-five individuals were found which extinguished either simultaneously or approximately so on either side of the twinning plane. A little more than half of these gave angles of extinction between 24° and 36°, the greater portion being less than 30°. This would seem to indicate, for a portion of the feldspar at least, a basicity not less than that of labradorite. The large variation in the angle of extinction on sections cut parallel to $\infty P\bar{\infty}$ must be interpreted as meaning an increasing acidity from the center outward. Judging from the manner of decomposition and general physical character, the feldspars must all belong to the same series, but it is difficult to assign their exact position on account of some apparently conflicting evidence. The paucity of calcite as a decomposition product in the rock, and the change to a soda rich mineral (analcite) indicate a soda feldspar; but the undoubtedly high extinction angle of a large proportion of the individuals would place them in the basic portion of the series. After digesting it long with concentrated hydrochloric acid the pulverized feldspar was apparently partly decomposed, thus allying it to labradorite. As a possible means of aiding the determination, a separation was attempted, using Klein's solution for the purpose of getting the specific gravity. A portion of the rock was pulverized sufficiently fine to be passed through an 80-mesh screen, and that which passed through the 100-mesh was rejected. Upon being placed in the solution the augite and magnetite immediately fell. The solution was then diluted until the separation of apparently pure feldspar was obtained. This was corroborated by a microscopic test. The specific gravity of this was found to be 2.511. A second separation was made at a greater density, using the material

which fell in the first trial. This gave a maximum specific gravity of 2.571, the powder in both cases appearing alike under the microscope. There was no point at which any large proportion of the feldspar came down. It fell little by little with increased dilution. The results obtained are so far below the specific gravity of any of the soda-lime feldspars that they can only be attributed to the dissemination of exceedingly minute particles of analcite through every portion.

Under the microscope the feldspars appear to be undergoing decomposition to several distinct products. The most prominent of these is a clear isotropic substance, identical in appearance with the analcite filling the angular spaces, even showing the same optical anomalies. In many instances this alteration has spread over nearly the whole crystal. In the case of some it has begun on the outside, in others from the center, leaving a mere shell. It is common to find that those crystals which contain much analcite are less altered to the other secondary products, such as kaolin and the green granular products. The analcite differs from that in the angular spaces between the crystals in being perfectly fresh. The analcite is often distributed through the crystals in angular sharply-defined areas, giving the appearance of a mosaic of the cuneiform characters of the quartz penetrations in graphic granite. (Plate 15, Fig. 2.) In these cases the remaining portions of the feldspar are perfectly clear and polarize brightly. When even but a small portion of the feldspar is left, it is perfectly clear. Those portions of the feldspars which join the angular areas of analcite, where the latter are more or less replaced by a green fibrous aggregate, are also invaded by the same along cracks and cleavage planes, and in extreme cases are almost wholly replaced by it. Decay of the feldspars to kaolin is also widespread. Sections made from many other dikes show much the same manner of decomposition for the feldspar. In every section the latter is more or less replaced by analcite, but kaolinic and green products are more characteristic.

Lamellar Pyroxene.—The pyroxenic component appears to be augite, but it exhibits some peculiar phenomena allying it to diallage. As distinguished from the orthorhombic pyroxenes, it gives

oblique extinction in the plane of the clinopinacoid, and the emergence of an optic axis in the orthopinacoidal section. The polarization colors are quite brilliant. It occurs partly in idiomorphic crystals and partly allotriomorphic with reference to the feldspar. It is very slightly pleochroic with pale brown to greenish tints. Numerous basal sections exhibit an octagonal form and very distinct prismatic cleavage. The idiomorphic individuals are elongated in the plane of the orthopinacoid to long tabular forms. Twinning is very common; in some individuals there are but two simple twins, in others a thin lamellar plate separates the two broad outer ones.

In addition to the twinning another divisional plane appears, which is so closely allied to it that, not until after close study and repeated examination, was it shown to be different. Twinning in augite takes place in the plane of the orthopinacoid, consequently sections cut in the plane of the clinopinacoid will extinguish symmetrically on either side of the trace of the composition plane, and, if the extinction angle is 45°, both will become dark at the same time. Twins cut perpendicularly to the prism will also extinguish simultaneously and parallel to the composition plane. This other parting in the augite of the Cuyamas dike takes place in the same plane as the twinning, and closely resembles it, but is distinguished by the fact that, in whatever position the section is cut, the two halves of the crystal extinguish simultaneously. Numerous individuals were examined which were cut in the clinopinacoid, or approximated it, and, with very few exceptions (twinned individuals), all extinguished simultaneously. The extinction angle was not 45°, and, consequently, as that is the only angle at which twins cut in that section could extinguish simultaneously, the phenomenon seen is not that of ordinary twinning. This plane, the trace of which is seen in the clinopinacoid and basal sections, is a very perfect one, geometrically considered. (Plate 15, Fig. 3.) It is distinguished by its regularity from ordinary cleavage, and is often so fine that it is inconspicuous. In some instances the parting does not extend to the borders of the crystal, and still more rarely there was observed a short parallel parting. A close examination of this plane with high powers showed that it was not possible to

consider it as being due to the interposition of an exceedingly thin lamellar twin, in which case the two outer twins would extinguish simultaneously. It could not be considered of secondary origin, for it is fully as prominent in the freshest crystals, seeming to have no connection with a cloudy fibrous appearance in many of them. It is quite possible, however, that it represents the junction of two individuals with the same molecular orientation, and that, instead of ordinary twinning, in which alternate individuals are reversed, in this case the reversion did not take place. An approximately basal section was observed in one slide in which normal twinning appeared, the two halves not extinguishing simultaneously, while in addition one of the halves contained the trace of this peculiar parting. This plane divided it into two slightly unequal portions, both of which showed the same polarization tints and extinguished simultaneously.

Another remarkable feature of the augite, quite distinct from the last, is the very perfect diallagic cleavage and the silvery lustered interior portion. In thin section the latter is indicated by fibrous cloudy areas, somewhat irregular in shape and generally confined to the central portion of the crystal. Plate 15, Fig. 3, is a good illustration of this decomposition. A cleavage plate parallel to the orthopinacoidal parting was obtained, showing the nature of the alteration. The fibers lie transverse to the *c* axis, fading out toward the periphery, their extremities being terminated by the traces of the planes of the prismatic cleavage. (Plate 15, Fig. 4.) In the hand specimen this cleavage is very strongly pronounced, and, judging from the manner in which the crystals split, it is not confined to one plane, but may be developed in any portion of the crystal. The perfect cleavage and silvery luster of the augite individuals in the hand specimen is one of the most striking features of the rock. This phenomenon undoubtedly represents the beginning of a change to diallage, but, instead of starting from the outside, as is usually the case, the alteration has commenced at the center, and the fibration has taken place transversely instead of longitudinally.

Analcite.—The first thing in the hand specimen that attracts one's attention is the presence of clear, glassy grains, with a faint iridescent luster. Under the microscope they are found to be

almost isotropic, exhibiting generally the faint double refraction in the form of stripes, so characteristic of analcite. The mineral proved to be soluble in hydrochloric acid, and the solution upon evaporation to dryness left crystals of sodium chloride. It was somewhat more difficultly fusible than is stated to be the case with analcite in the works upon blowpipe analysis. The specific gravity ascertained by Klein's solution was 2.266. The analcite occurs under four different conditions in the rock, namely: (1) Lining the sides of cavities frequently two centimeters in longest diameter; (2) filling the angular spaces between the divergent feldspar crystals, spaces from microscopic size up to eight millimeters in diameter; (3) replacing the feldspars; and (4) in one of the dikes, in the form of hexagonal or rounded grains partly inclosed within the feldspars. It is possible that the larger cavities about which the analcite is crystallized are of secondary origin, as they occur only locally and in portions of the rock which are most decomposed, but they do not differ materially in character from some of the larger spaces entirely filled with analcite, on which, as in the case of the crystals lining the cavities, striations appear. Faces of the trapezohedron, the common crystallographic form of analcite, were observed on some of the crystals lining these cavities.

At the termination of the crystallization of the feldspar and augite sharply angular areas were left between the divergent crystals, which are now filled with analcite and its decomposition products. To account for the presence of the analcite we have to adopt one of four hypotheses: The possibility of its being primary, of its derivation from the feldspar, of its resulting from the decay of some unknown soda-rich mineral, or of its introduction into the rock subsequent to its solidification. Of the first there is no confirmatory evidence whatever. With one exception analcite has always been considered of secondary origin. The analcite of the basalt described by Lindgren,* from Montana, is considered by him as primary. This opinion is based on the fresh condition of the rock and the predominance of hexagonal sections among those

*Eruptive Rocks from Montana, Proc. Cal. Acad. Sci., Vol. III., 1891, p. 55.

which are idiomorphic. He says: "Nepheline could, of course, not be the mineral from which the analcite might be derived, the form of the crystals prohibiting that supposition." It would appear to the writer that this could be no objection, as nepheline frequently shows hexagonal sections. No evidence is at hand to support the view of its subsequent introduction into the rock. Its apparently uniform distribution through the whole of the extensive eruptive mass which has not been fissured or sheared makes this view seem utterly untenable. Although no direct evidence appears in the rocks under discussion in favor of the supposition of the derivation of the analcite from an unknown soda-rich mineral, it seems probable that such is its origin. The test for sulphur gave a negative result, while that for chlorine resulted in only a trace. The minerals of the sodalite group are thus excluded. Nepheline is the only remaining soda mineral from which it might be derived, and it will be shown how closely the rock resembles some from other localities known to contain nepheline or eleolite. A slide from one of the smaller dikes exhibited a number of areas of an isotropic substance partly inclosed in the feldspars and idiomorphic with reference to them. Several of these have a rude hexagonal outline, and one in particular is very regularly hexagonal. (Plate 15, Fig. 5.) They are not apatite, as is shown by the partial decomposition and absence of an interference figure, and are, without doubt, referable to analcite. Scattered through them are small crystals of a substance which has the character of calcite. Analcite also occurs in the same rock, in wedge-shaped areas between the feldspars. In the one case the analcite has certainly replaced a soda mineral, perhaps nepheline, and in the other its origin is doubtful. It is possible a part of the nepheline in the dike crystallized before the feldspar, and the remaining portion, if such existed, as the last constituent. The feldspar, judging from the extinction angle, all belongs in the basic portion of the series. Even on the supposition that it were albite of normal composition, and form fifty per cent. of the rock, the percentage of soda which should be present in the rock would fall below that given in the analysis. Confirmatory, then, of the view of the original derivation of the analcite from nepheline is the relative basicity of the feldspar and the high per-

centage of soda, as shown by the bausch analysis. Opposed is the low percentage of lime, and the possibility that the feldspar either contains a sufficient amount of soda, or that it has been introduced subsequently. In the light of all the facts it seems to the writer that the hypothesis of the derivation of the analcite from nepheline has the most in its favor, although several things are still unexplained.

The rock as a whole has close affinities with those of the disputed teschenite group, but contains no mica or hornblende. Rosenbusch* holds that the analcite in rocks of this class, in which nepheline cannot be detected, has nevertheless been derived from nepheline, that if it were not derived from nepheline the rock must have had originally a remarkable porous structure, and that he does not see how the alteration of a lime-rich feldspar can result in a soda zeolite. Such a porous structure (miarolitic) as must have existed in the rocks under discussion, had the wedge-shaped areas been left empty at the close of the solidification of the magma, is unknown in rocks of the diabase type.

Rohrbach,† who subsequently studied the rocks termed teschenites by Tschermak, was unable to find nepheline in any of them, and reached the conclusion that the analcite owed its origin to the feldspar. His description of the manner of the occurrence of the analcite is very similar to that observed in the Cuyamas eruptive. He mentions analcite as present in angular spaces between the feldspars, also in shreds and veins with sharply defined boundaries replacing them, pseudomorphs of analcite after feldspar also being noted. The analyses given by him show, however, a very much less amount of soda than is found in the rock under discussion.

The feldspar in the rock studied by Rohrbach exhibited a zonal structure, and he considered that it represented all degrees of basicity from anorthite to albite. If this view is correct, the feldspar would furnish quite a percentage of soda. Macpherson, in his study of the teschenites of Spain, as cited by Rosenbusch, reached much the same conclusion as Rohrbach.

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*Mikroskopische Physiographie der Massigen Gestine, p. 253.

†Ueber die Eruptivgestine in gebite der Schlesich-Mahrischen Kreideformation. T. M. P. M., 1886.

Teall* describes a very similar rock consisting of prismatic augite, feldspar much altered, analcite, natrolite, magnetite, brown mica, and green decomposition products. He says: "Unless soda has been introduced, the abundance of analcite would imply either the existence of nepheline or of a soda-lime rather than a lime-soda feldspar."

The description given by Williams† of the eleolite syenite rocks of Arkansas is very interesting in connection with the study of this rock. Several short extracts will be given to illustrate the structural affinities of those rocks with the Cuyamas eruptive. He says: "Eleolite never occurs in this rock in idiomorphic crystals, but always in wedge-shaped or polyhedral masses which take their exterior form from the minerals by which they are surrounded. * * * It is a very common thing to find this mineral altered to analcite; in some cases so complete has been this change that in many sections no remnant of the original substance can be found. * * * The analcite seems to have eaten into the feldspar wherever it could get a chance, and many feldspars may be found whose centers have become almost entirely changed into analcite, while others have been eaten away on one side, the rest remaining intact." Williams‡ also describes a miarolitic structure in the Magnet Cove eleolite syenite. The rock is much decomposed and the eleolite has nearly disappeared. "It contains many cavities into which the feldspar crystals extend and show by their perfect crystalline forms that these spaces were originally empty or were filled with some late formed mineral which has since been decomposed." This description will apply to both the Cuyamas and Oceanic dikes, both augite and feldspar projecting into the analcite areas with perfect idiomorphic forms. (Plate 15, Fig. 6.) It is probable that these dykes were not originally miarolitic, but that the spaces must have been filled by some late formed mineral rich in alkali. It would hardly be reasonable to suppose that a miarolitic structure existed so uniformly in all the dikes described, both large and small. Carry a step farther the decomposition of the eleolite of the Arkansas rocks, and we have a

*British Petrography, p. 191.

†Arkansas Geological Survey, Igneous Rocks, pp. 66. 79.

‡*Ibid.*, p. 232.

remarkable parallel with that of the best preserved of the rocks described in this paper.

Wolff* describes a rock which he terms a tephrite, from the Crazy Mountains, Montana, in which the nepheline is said to lie between the feldspars in imperfect crystals or to fill triangular spaces. In another publication† he describes acmite trachytes from the same region in which nepheline occurs, filling angular areas between the other components.

The third important condition under which the analcite occurs, that of replacing the feldspars, has already been described. The change to analcite does not seem to have taken place from the wedge-shaped areas between the feldspars, but to have gone on independently in various portions of the crystals. The appearance in many places, where the isotropic areas are so sharply defined, is that of a paramorphic rather than a chemical change. This replacement of feldspar by analcite has been noted in all the rocks of this class, as well as in the eleolite syenites of Arkansas and the nepheline rocks of Montana, and does not seem to depend on the percentage of soda in the feldspar. This phenomenon seems to be mostly confined to rocks rich in nepheline and related minerals, or to those in which they are supposed to have existed.

The analcite occupying the wedge-shaped areas is undergoing decomposition to a green fibrous aggregate. The fibers extend inward from the outer edge, often aggregated in radial tufts. They are non-pleochroic, polarize quite brilliantly in greenish to reddish tints and extinguish parallel to their long diameters. These fibers often exhibit an undulate form and terminate in the analcite in slender branching needles. They are almost colorless toward their extremities, but being doubly refracting are strongly marked from the analcite under crossed nicols. After treatment with hydrochloric acid and fuchsine, these fibers were stained a deep purple. A specific determination was found to be impossible on account of the small dimensions and lack of crystal outlines.

In many of the sections, especially those from the smaller dikes,

*Notes on the Petrography of the Crazy Mountains. North. Trans. Survey.

†Acmite Trachyte from the Crazy Mountains, Montana. Bull. Museum Comp. Zoölogy, Harvard College, Vol. XVI.

the analcite is largely replaced by natrolite in radial aggregates. It also occurs in veins traversing the rock.

Secondary Minerals in the Analcite.—The polyhedral or wedge-shaped areas of analcite contain two secondary minerals in a fresh condition. One, having the character of prehnite, occurs in clear grains and idiomorphic crystals projecting into the analcite from the borders or wholly inclosed in it. The other is probably feldspar, bordering the analcite and apparently replacing that substance.

The prehnite crystals are in some cases more than a millimeter in diameter, but generally smaller, and are found in many of the analcite areas of all the slides prepared from the large dike. (Plate 16, Figs. 1 and 2.) It is as clear and colorless as the analcite, but in ordinary light is distinguished from the latter by the high index of refraction, producing an apparently rough surface and high relief. The polarization colors are very brilliant. The optical anomalies often seen in prehnite do not appear. The form of the idiomorphic individuals is commonly hexagonal or octagonal. No trace of cleavage is to be seen. Two sections were obtained cut perpendicular to a bisectrix. Each of these showed a bi-axial interference figure, in which the dispersion was apparently symmetrical with reference both to the plane of the bisectrices and that perpendicular to it. When the crystallographic boundaries are present the extinction is parallel to one edge, indicating an orthorhombic mineral. One of the sections referred to gave a negative, the other a positive sign. The dispersion is that given for prehnite, red being less than blue. Several treatments with hot hydrochloric and sulphuric acids failed to decompose it; the only effect produced seemed to be a roughening of the surface and the appearance of irregular cracks extending inward from portions of the surface.

Owing to the minute size of the crystals, and to the fact that the optical properties of this mineral are identical with those of olivine, much difficulty was experienced in making a positive determination. The greater resistance of the mineral under discussion to acids and the unlikelihood of olivine occurring as a secondary product, made the determination in favor of prehnite probable. To make this certain a few grains were obtained perfectly free from the other components and treated with hydrofluosilicic acid. This developed

characteristic spindle-shaped crystals of fluosilicate of calcium. As certain varieties of olivine contain lime, it was necessary to determine whether alumina was present or not, prehnite being a lime alumina silicate, while olivine contains no alumina. For this purpose Behren's method was used. A few very minute grains were obtained, and, after being reduced to a powder, were treated with hydrofluoric acid. This decomposed the mineral, and upon evaporation a few drops of pure sulphuric acid were added and the mass reduced to a sulphate. After evaporation the residue was diluted slightly with water and the solution was ready for examination. A microscopic examination showed it to be filled with minute rod-like crystals of gypsum. A drop of cæsium sulphate was added to part of the solution on a glass slide. At first no reaction took place, but upon standing a day numerous small crystals of cæsium alum separated out, having the form of very perfect octahedra. This reaction showed that the mineral was not olivine, and inasmuch as lime was abundant and magnesia not definitely recognized, the determination of the mineral as prehnite was considered as correct. As a check upon the above, the specific gravity of several grains was determined by Klein's solution and found to be 2.894, the specific gravity of prehnite ranging from 2.80 to 3.

Many of the analcite areas contain large numbers of the prehnite individuals, only a part of which are idiomorphic, and in rare instances a single crystal was observed nearly filling a wedge-shaped area (Plate 15, Fig. 6), being partially allotriomorphic. The perfect idiomorphic boundaries of those individuals lying farther within the analcite, and the more irregular granular form of the smaller ones clustered near the outer edge, and their lack of attachment to the feldspars bounding the analcite, suggest very strongly their formation within the analcite and not in a cavity. Many instances appear of prehnite crystals wholly separated from the feldspar by the analcite, and in some cases by secondary feldspar. The green fibrous material eating into the analcite has slightly affected a portion of the prehnite crystals.

The question may arise as to whether the idiomorphic outline of many of the prehnite individuals does not make their formation from the analcite impossible. It might seem more likely that they

grew as druses in originally empty spaces in the rock. This would of course affect the question of the original presence of nepheline. In the first place it may be said that the condition of occurrence of several of the minerals of this rock including the prehnite is quite peculiar. It seems to the writer probable that the prehnite was formed either during the alteration of the nepheline, from which the analcite is supposed to have been derived, or directly from the analcite itself. In many of the feldspar crystals the alteration to analcite has left as sharply defined rectilinear lines as are shown to exist between the analcite and the prehnite, but in the former case there is no tendency to the formation of crystal boundaries. The writer does not deny that there may have been open spaces left in portions of the rock mass at the time of solidification; the presence of analcite partly filling some of these in the largest secondary dike supports that view.

The discussion of the question concerning the original presence of nepheline has been given in another place. In addition it might be said that the existence of a similar structure (the polyhedral areas filled with analcite) in all the known bodies of rock of this type, and in this type only, in the Coast Ranges—bodies of varied size, which must have solidified under different conditions—is inconceivable unless we postulate some original inherent peculiarity of composition. This is best illustrated in the case of the Cuyamas eruptive. The polyhedral areas filled with analcite are found to occur in a similar manner in the large primary mass, which is a thousand feet across, as in the numerous secondary dikes from four inches to twenty feet wide. It is hardly possible that similar conditions of solidification could have existed in bodies of such greatly diverse size. While the writer does not hold that the original presence of nepheline can be demonstrated (unless in the case of one dike in which hexagonal areas of analcite occur), yet, taking everything into consideration, there seem to be fewer difficulties opposed to that view than to any other.

The other mineral, supposed to be feldspar, is found bordering the analcite and growing inward. It generally occurs as an irregular border of microscopic proportions. Sometimes the outer edge is wavy (Plate 16, Fig. 3), at others rectangularly serrated. It is

perfectly clear, does not polarize brightly, and is unaffected by acids. The large areas show the dark arm of a biaxial interference figure. The manner of occurrence would lead to the belief that it is a soda-rich feldspar. Several instances were observed of a twinned feldspar, fresh in appearance, and showing a small extinction angle, which was also inclosed in the analcite and apparently of secondary origin. One of these has a regular and well-defined crystal boundary. Secondary feldspar is also found in and on the edges of the primary feldspar.

Titaniferous Magnetite.—The oldest separation from the magma is magnetic iron oxide containing titanium. It occurs in irregular grains, hexagonal and rectangular forms, and long slender rods sometimes united in skeleton crystals. These penetrate all the other primary components of the rock. In some of the hand specimens these rods are plainly visible, being a millimeter or less in width and ten to fifteen millimeters long. It is present in all the dikes, but the proportion varies greatly. Plate 16, Fig. 4, illustrates a rock in which there is an uncommonly high percentage of this mineral.

CHEMICAL CHARACTER.

The writer is indebted to Mr. V. Lenher, of the Department of Chemistry of the University of California, for the analysis (I) of the large secondary dike in the Cuyamas region given below. There is inserted for comparison, an analysis (II) given by Rohrbach* of a typical teschenite; of a theralite (III) by Wolff†; and of a plagioclastic eleolite syenite (IV) from Arkansas.‡

*T. M. P. M. 1886.

†Notes on the Petrography of the Crazy Mountains, Montana.

‡Geological Survey of Arkansas. Igneous Rocks, p. 139.

	I.	II.	III.	IV.
SiO_2	50.55	47.41	43.175	58.74
Al_2O_3	20.48	18.65	15.236	20.85
Fe_2O_3	2.66	10.21	7.607	4.15
FeO	4.02		2.668	.....
CaO	7.30	7.17	10.633	0.36
MgO	4.24	5.06	5.810	0.22
K_2O	2.27	2.06	4.070	4.23
Na_2O	8.37	4.90	5.680	9.72
SO_3	.....	.....	0.940	.....
H_2O	.44	5.05	3.571	1.82
Cl	Trace	.....	.....	.....
	100.33	100.52	99.390	100.09

It is very difficult to arrive at any conclusion as to the composition of the different components of Cuyamas dike from the analysis. The rock is remarkable for the high percentage of alkalies and alumina and the low percentage of calcium. The proportion of soda is too great for even a soda feldspar, although the high extinction angles forbid that supposition. The presence of so much potash with no potash feldspar is another thing which it is difficult to explain. If a portion of it is contained in the analcite, that would favor the view of the derivation of that mineral from nepheline, which always contains potash. The percentage of calcium is too low for the estimated proportion of augite in the rock, unless it be of very peculiar composition, to say nothing of that required for the feldspars with so high an extinction angle. The analysis given by Rohrbach is of a rock containing labradorite feldspar. The amount of potash and calcium agrees very closely with that of the Cuyamas dike, but the soda is less. The feldspar in the Arkansas rock, according to Williams, lies between albite and labradorite, although the extinction angles correspond to labradorite. This rock contains twenty-five per cent of eleolite, but the analysis shows a comparatively small increase of soda over that of the Cuyamas dike. Williams considers the rock closely allied to the theralites in mineralogical composition.

Although the actual proof is not possible, it seems to the writer that the conclusion is reasonable that some primary soda silicate (probably nepheline) formerly occupied the wedge-shaped areas. The description given by Rosenbusch and others of the teschenites corresponds very closely with the facts observed in the rocks which form the subject of this paper.

OCEANIC DIKES.

The most important development of this series of dikes is near the Oceanic quicksilver mine, six miles east of Cambria. Two to four dikes of varying width and separated by narrow strips of upturned Tertiary strata were traced for at least twelve miles. There is a great similarity in all, and they have undoubtedly issued from one parent magma. At one locality an oil well was sunk nearly seven hundred feet in a strip of Tertiary strata lying between two of these dikes. In the bottom a crystalline rock was encountered which in all probability marks the point at which junction takes place. The degree of decomposition of these dikes appears to be very great. Except in the bottom of the cañons the rock is scarcely more coherent than the main body of the Cuyamas dike. At the foot of the grade leading from Cambria across the mountains, there are shown some remarkable examples of shelly spheroidal weathering. Many of the spheroids are a foot in diameter with clayey matter between them, and peel off in very regular concentric shells, one-third of an inch in thickness down to a more solid core.

A microscopic study of these rocks confirmed to a considerable degree the appearance of decomposition. In a general way there are two macroscopic differences, the lighter colored facies in structure and appearance much resembling the Cuyamas dike, except that no analcite is visible to the unaided eye; and the dark-colored facies, very rich in iron, in which the individual components cannot be determined without the microscope. The most of the lighter-colored specimens were collected from the most westerly dike. Sections made from this dike showed the existence of feldspar, augite, olivine decomposed to serpentine, analcite, magnetite, and green decomposition products. The structure is typically diabase granular, the feldspar crystals penetrating and frequently almost

isolating portions of the same augite individual. The feldspars show twinning (albite law) and high angle of extinction in a manner similar to that of the Cuyamas dike. Tabular sections are less abundant, lath-shaped forms predominating. But few feldspar individuals have a fresh appearance, having been changed to kaolinic matter or penetrated and largely replaced by green decomposition products, originating in the olivine and angular analcite areas. A replacement of the feldspars by analcite has taken place in a manner similar to that before described, but it is less pronounced. This change is more noticeable in the fresher individuals.

The augite is similar to that before described, but more rarely shows crystal forms and never that distinct orthopinacoidal cleavage. In most specimens it is the freshest component of the rock.

To the decay of the olivine is due in part the alteration of the other components. All sections show areas of green matty and granular material, which, from the frequent hexagonal forms with clear centers and dark borders, filled with magnetite granules, and very pronounced reticulated structure, are judged to represent olivine. The centers are in many cases brilliantly polarizing and intersected by clear rectangular lines. The decomposition products are serpentinous in character.

There are other sharply angular areas between the feldspars filled with green matty and fibrous material, which, it is believed, has replaced analcite, as in places that isotropic mineral still remains. (Plate 16, Fig. 5.) On account of the decomposition of the analcite filling these wedge-shaped areas, it was distinctly determined in only two slides, but it was undoubtedly present at one time in all. The freshest portion of the dike has a very peculiar structure, crumbling to spherical bodies fifteen to twenty millimeters in diameter. Titaniferous magnetite is present in this dike, as before described, in the form of grains and long rods.

In the dark and fine-grained types confined to the three easterly dikes, as in the one just described, it is often impossible to obtain coherent specimens in place, and the exact position in the dike of many studied is unknown. Nearly all the sections made from these rocks show a much fresher condition of the feldspar and olivine. The former are more lath shaped, and high angles of

extinction are common. The olivine is more abundant, but in manner of decay resembles that just described. The decomposition products of this mineral have so penetrated the angular spaces, as well as the feldspars themselves, that the presence of analcite was not detected. Magnetite is very abundant, both as a primary constituent and as secondary dust, in the olivine decomposition products. Opaque granules are numerous in the feldspar of one slide. In another it is penetrated by minute clear rods, probably apatite.

There is one type of the dark rocks of uncommon interest. As usual the feldspar predominates, but it is comparatively fresh. The augite is also fresh. The amount of serpentinous matter showing the appearance of olivine decomposition is large. This serpentinous substance has spread through the rock, almost isolating individual feldspar crystals. It also appears in angular spaces of various sizes, spaces which resemble those occupied by analcite in the other specimens. Portions of these spaces not filled with this green matty material are occupied by a clear substance in the form of aggregated individuals, showing the polarization of calcite. Treated with dilute acid this is decomposed with effervescence. Lying either in the green products, partially in the calcite, or on the borders of the angular spaces, are spherulites of a very peculiar character. (Plate 16, Fig. 6.) They generally possess a dark center, around which are placed wedge-shaped plates to form an almost perfect sphere when not interfered with. The outer contour of the spherulites is bordered by a dark crenulate line, a short distance within which is another crenulate circle formed of two lines. Under crossed nicols a dark cross is seen, which even extends at times beyond the boundary of the spherulite proper to radially arranged calcite individuals. The spherulite itself has a very pale yellow color, while the carbonate is colorless. After treatment with hot concentrated sulphuric acid and staining with fuchsin, the centers and borders only are seen to have been affected. The invariable position of the spherulites and their association with calcite would indicate that they were not formed primarily in a glassy portion of the rock, but are secondary products partly replacing some easily decomposable primary mineral (possibly one of the sodalite group). No known

secondary spherulites except chalcedony would resist the action of acids, and these cannot be referred to that substance.

EAGLE RANCH OCCURRENCE.*

A small dike, which should undoubtedly be classed with the analcite diabases above described, is found on the Eagle Ranch, in the heart of the Santa Lucia Range. It outcrops in the center of a conical hill, formed of lower Cretaceous sandstone and shale. Microscopically it very closely resembles the secondary dikes of the Cuyamas eruptive, but is more decomposed, no analcite being visible. The feldspar has a dull luster, but the augite appears quite fresh. Much greenish material is scattered through the rock. The structure is diabase granular.

Microscopically the specimens appear very much decomposed. The short lath-shaped feldspars show traces of polysynthetic twinning, but are completely decomposed to cloudy kaolinic masses. It is not possible to measure the extinction angle. The augite is fresh in some specimens, in others considerably clouded. It has a pale brownish color, and shows no pleochroism. A pale green substance, somewhat fibrous, is very abundant in the thin section. It fills angular areas between the feldspars, and in many cases has invaded the latter. This substance closely resembles that which has replaced the analcite in the more altered of the dikes already described. In its manner of occurrence it is precisely similar. No analcite was detected in any of the specimens, but there seems to be no doubt about its original presence. Secondary feldspar appears quite frequently on the borders of the green areas. Magnetite is present in the form of skeleton crystals.

None of the specimens exhibit any peculiarity not before described, and, owing to the extreme degree of decomposition, a more detailed description will not be attempted.

CONCLUSION.

No rocks of the character of those described in this paper have been noted before on the Pacific Coast, while none so closely related

*The writer's attention was called to this dike through the kindness of A. F. Benton, superintendent of the Eagle Ranch.

to the so-called teschenites have been found in the United States. While the original presence of nepheline has not been positively demonstrated, the phenomena shown mostly favor that supposition. The designation analcite diabase is used, although it seems to the writer that the rock really belongs among the theralites.

The most important peculiarities of the rock are the following:—

The combination of diabase granular or ophitic structure with the panidiomorphic, the augite in the main body of the Cuyamas dike being allotriomorphic, in the smaller secondary dikes partly or wholly idiomorphic.

High extinction angles in the feldspar associated with a low percentage of lime, as shown by the analysis.

The existence in the augite of a peculiar parting, which, while conforming to the position of the diallagic cleavage, yet seems distinct from it.

The beginning of alteration in the central portion of the augite crystals, resulting in silvery white, diallagic cleavage faces.

The idiomorphic forms of both feldspar and augite with reference to the analcite areas.

The presence of a large percentage of analcite under four conditions, namely: Crystallized and lining cavities in the rock; filling angular spaces between the older components; replacing the feldspars; and in the form of hexagons, idiomorphic with reference to the feldspar.

Prehnite, supposed to have been formed either in the analcite or during its derivation from some primary component.

Secondary feldspar replacing the analcite.

High percentage of soda and absence of sulphur and chlorine, pointing strongly to the presence primarily of nepheline.

Presence of secondary spherulites of an indeterminate mineral in one facies of the rock.

Geological Laboratory,
University of California, January 15, 1895.

EXPLANATION OF PLATES.

The letters in the figures refer to the following minerals: F, feldspar; P, pyroxene; O, olivine; A, analcite; SF, secondary feldspar; M, magnetite; Pr, prehnite; C, calcite; G, green matty areas.

PLATE 15.

FIGURE 1.—Main body of the Cuyamas dike. This section shows the larger undecomposed areas of analcite and the diabase granular structure. × 25.

FIGURE 2.—Large secondary dike (Cuyamas eruptive). The angular form of the analcite replacing the feldspar is characteristically illustrated; also the fibrous alteration which the analcite in the wedge-shaped areas is undergoing. × 35.

FIGURE 3.—Large secondary dike (Cuyamas eruptive). The main feature in this illustration is a basal section of the lamellar pyroxene exhibiting a fibrous center due to alteration, and the peculiar orthopinacoidal parting. × 35.

FIGURE 4.—Diallagic cleavage plate showing transverse fibration. The whole width of the crystal is not shown. The fibers are seen to terminate as a general thing on the traces of the prismatic cleavage. × 25.

FIGURE 5.—Small secondary dike (Cuyamas eruptive). One rudely hexagonal form of analcite appears in contact with a wedge-shaped area of the same mineral. × 35.

FIGURE 6.—Large secondary dike (Cuyamas eruptive). The prehnite is seen to have its form partly conditioned by the shape of the analcite area in which it occurs. × 35.

PLATE 16.

FIGURE 1.—Section from large secondary dike (Cuyamas eruptive). This section shows the prehnite crystals occupying a portion of an angular analcite area. The individuals do not seem to have grown from the feldspar inward, but to have been formed within the analcite. × 35.

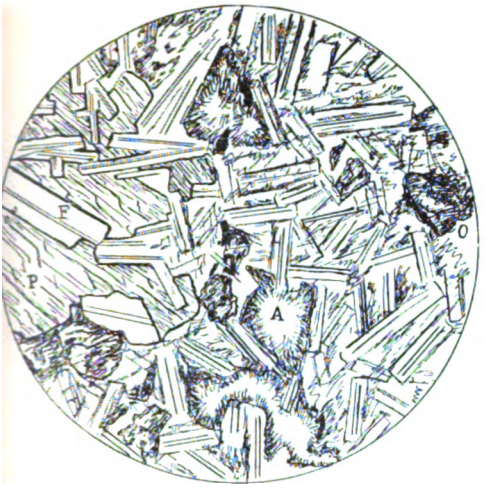
FIGURE 2.—Large secondary dike (Cuyamas eruptive). The characteristic features of this section are the sharply defined areas of analcite in the feldspar, the idiomorphic prehnite, the fibrous alteration product of the analcite, and the rod-like form of the magnetite. × 35.

FIGURE 3.—Small secondary dike (Cuyamas eruptive). The important feature of this section is the presence of a large amount of secondary feldspar replacing the analcite. × 35.

FIGURE 4.—Section from a small dike (Cuyamas eruptive). Titaniferous magnetite is the characteristic feature of this section. The mineral is present in rods and more or less regular polyhedral forms. × 35.

FIGURE 5.—Oceanic eruptive showing the angular analcite areas penetrated by the short lath-shaped feldspars. × 35.

FIGURE 6.—Section showing the spherulitic facies of the Oceanic dike. The feldspars are comparatively fresh but are almost inclosed in the calcite and green matty areas. The spherulites are always associated with the secondary products. × 35.



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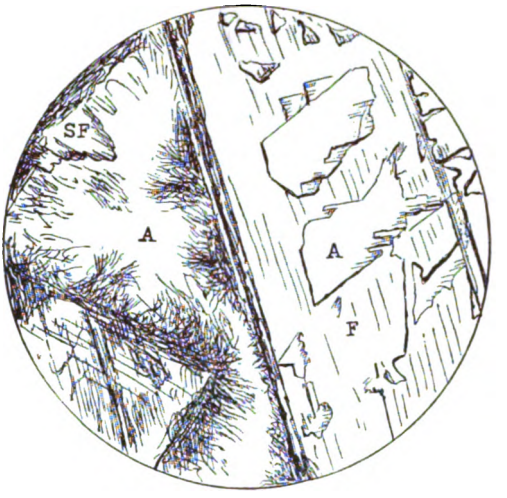

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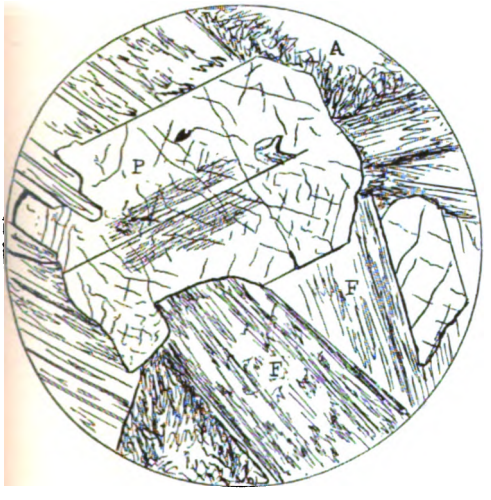

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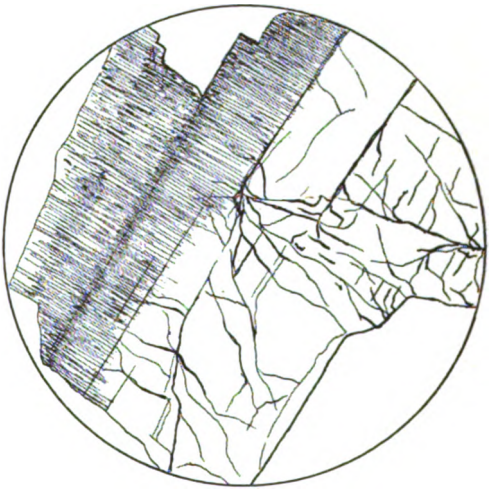

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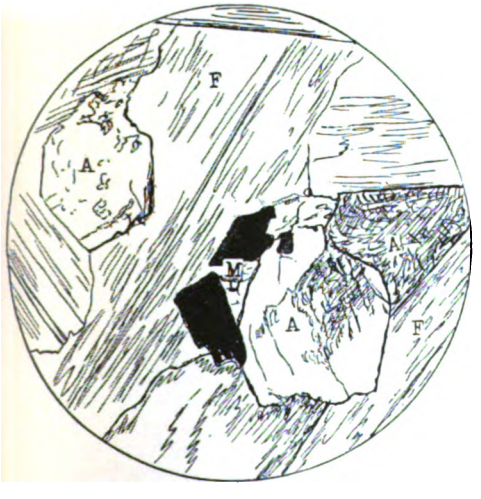

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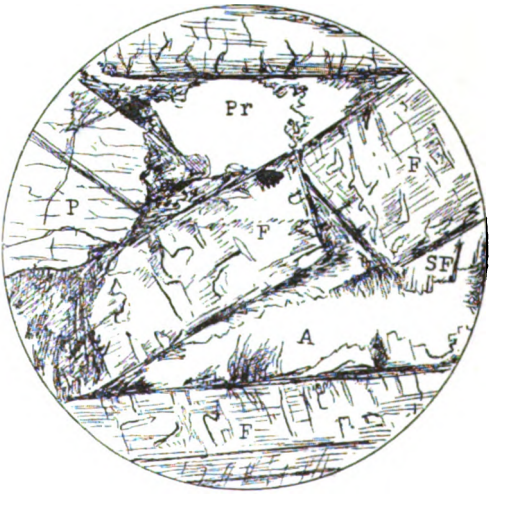

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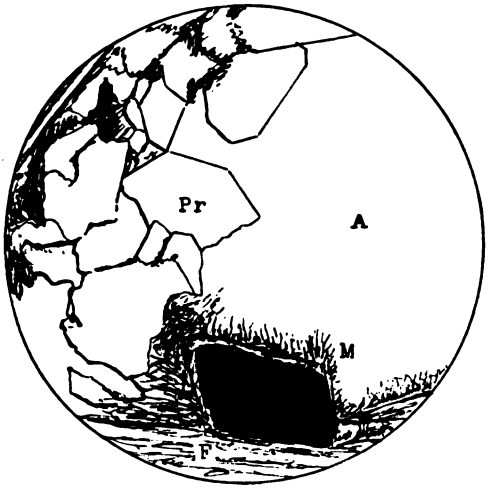

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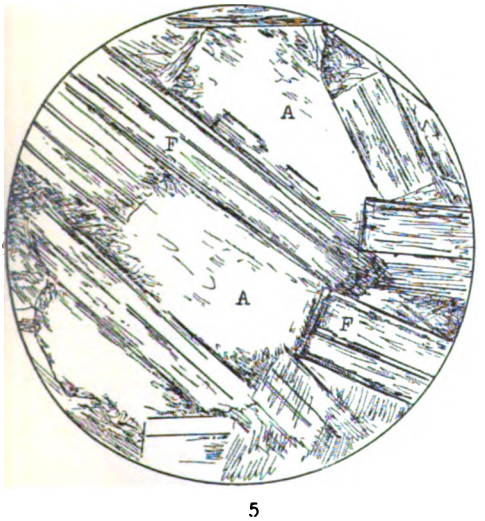

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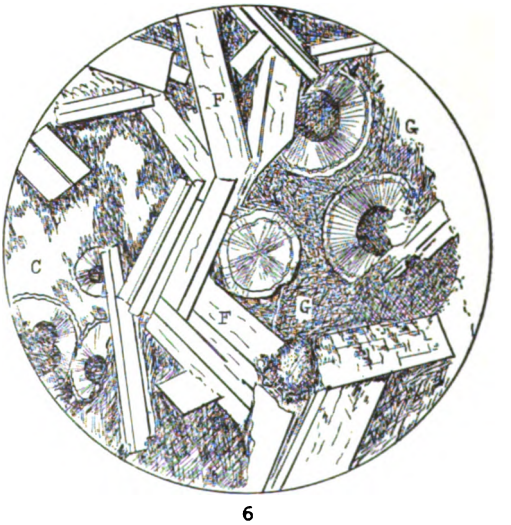

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THE STRATIGRAPHY OF THE CALIFORNIA COAST RANGES

BY H. W. FAIRBANKS

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INTRODUCTION.

In a recent publication the writer presented a résumé of the present state of knowledge of the geology of the California Coast Ranges.[1] It is intended to devote the present article partly to a more detailed statement of views expressed in that paper on the relation of the Miocene, Upper and Lower Cretaceous to each other, which could not be fully discussed for lack of space, and partly to the presentation of additional evidence in support of the writer's published views concerning the existence of a pre-Cretaceous (pre-Knoxville) series of rocks in the Coast Ranges. Most of the observations on which the opinions presented are based were made during the summers of 1891–2–3. Valuable additions were made the past fall, when in company with Mr. F. M. Anderson, a student in Stanford University, a three weeks' trip was made through the Santa Lucia Mountains in Monterey and San Luis Obispo counties.

[1] Bull. Geol. Soc. Am., Vol. VI., 71–102.

CRYSTALLINE BASEMENT COMPLEX.

Considerable areas of granite, crystalline schists, and limestone appear at many points in the Coast Ranges between Point Reyes and Ventura county. No information has yet been gained of the age of any portion of this basement complex, beyond the fact that it underlies unconformably the most ancient uncrystalline rocks which are probably not older than the Jurassic. It would appear that the granite cannot be correlated with that which was irrupted at the close of the Jurassic in the Sierra region. It seems highly probable, from our present knowledge, that a long period of erosion, during which these crystalline rocks were much more prominently exposed than at present, ensued between the upheaval and metamorphism of the schists and limestones, and the deposition of the lowest uncrystalline strata.

GOLDEN GATE SERIES.

Definition.—Between the lowest recognized Cretaceous and the basement complex is a series of rocks separated from both by nonconformities, and everywhere characterized by rather peculiar lithologic features. For this collection of strata, consisting chiefly of jasper, sandstone, shale, and slate, typically developed about the entrance to San Francisco Bay, the designation Golden Gate series is proposed. According to our present knowledge these rocks form a conformable series of strata with a remarkable similarity of character through their whole extent. The scanty fauna thus far known indicates that it does not embrace a great range of geological time, although its thickness is very considerable. The series has been recognized by the writer from central Santa Barbara county northwestward through the Coast Ranges to the Klamath Mountains. On the western slope of these mountains it has been traced to the Oregon line, and it undoubtedly extends farther. Until recently the series has been considered, by all geologists who have published results of work in the Coast Ranges, not older than the Knoxville, of which it has often been thought to be a metamorphosed portion. In 1892 the writer first advanced the view that these rocks were

not a portion of the Knoxville,[1] but that they underlaid it unconformably. Since then in other publications[2] additional evidences have been given of the geological independence of this series, of its distinct lithological character, and of its extent in the Coast Ranges. To the writer the evidences supporting this view seem to be conclusive. Nevertheless, the old view that these rocks constituted a metamorphosed portion of the Knoxville has been accepted so long, and has become so current in geological literature, that the new one has been looked upon with more or less doubt. The writer ventures to assert, however, that if the geology of the Coast Ranges had never been touched until today, the confounding of the Knoxville with the older series beneath never would have occurred. In the light of these conditions it has seemed best to continue to put on record all observations which would aid in bringing out a full recognition of the important fact that there is an uncrystalline series of rocks in the Coast Ranges beneath the Knoxville. The importance of the correct classification will be understood when it is stated that the strata included in the Golden Gate series extend for a distance of 500 miles through California, and for an unknown distance in Oregon. The recent field work in Monterey and San Luis Obispo counties has been so fruitful in positive results that the existence of a pre-Knoxville series of uncrystalline strata must be considered proved.

Lithologic character.—One of the distinct features of this series of rocks is its peculiar and comparatively uniform lithologic character. In general it is so different from that of any of the younger formations that it can be used as a criterion of distinction by one familiar with the general character of the formations in the Coast Ranges. This becomes of the greatest value when there is taken into consideration the scarcity of fossils and the rare occurrence of distinct contacts. The jasper has until recently been considered a metamorphic rock. In a paper read before the Geological Society last August, the view was advanced

[1] American Geologist, Vol. IX., 153–166.

[2] American Geologist, Vol. XI., 69–84. Bull. Geol. Soc. Am., Vol. VI., 71–102.

by the writer that the jasper is not metamorphic, but that it is formed to a considerable extent of the remains of siliceous organisms of the radiolarian type. This opinion was based on the study of a number of thin sections of the rock from widely separated portions of the Coast Ranges. F. Leslie Ransome has recently announced the discovery of the first radiolarian remains found in a state sufficiently well preserved for description. Many specimens of jasper were collected on the recent trip through Monterey and San Louis Obispo counties, and nearly all showed the radiolaria visible to the unaided eye. The best were obtained from a large outcrop of greenish white jasper on the Eagle Ranch, six miles northwest of Santa Margarita. A microscopic study shows that portions of this rock are made up almost wholly of radiolaria which are in a better state of preservation than any previously found, fifteen or more specific forms being made out. The jasper beds vary from a few feet to more than a hundred feet in thickness, and exhibit more or less distinctly a banded structure. The bands are often contorted so as to present a beautiful wavy appearance. The accompanying illustration is from a photograph of a magnificent outcrop on the coast of Monterey near the mouth of the Sur River. It illustrates both the banding and the wavy structure. Comparatively uniform conditions must have existed over the whole of the area covered by the Golden Gate series, where the rocks were being deposited, for the jasper beds are found almost everywhere that the rocks of this series are exposed. Similar conditions did not obtain during the Cretaceous, for jasper is not known in any beds of that age on the Pacific coast. The series of beds of which the jasper forms such a striking feature undoubtedly possess a great thickness, but they have not yet been studied sufficiently in regions where the greatest development occurs to admit of any definite statement of their thickness. It is not probable that the jasper is confined to one horizon in the series, and the strata have been so sharply folded, shattered, and crushed together by orographic movements, as well as by the intrusion of numerous eruptives, that its study is accompanied by uncommon difficulties. Sandstone

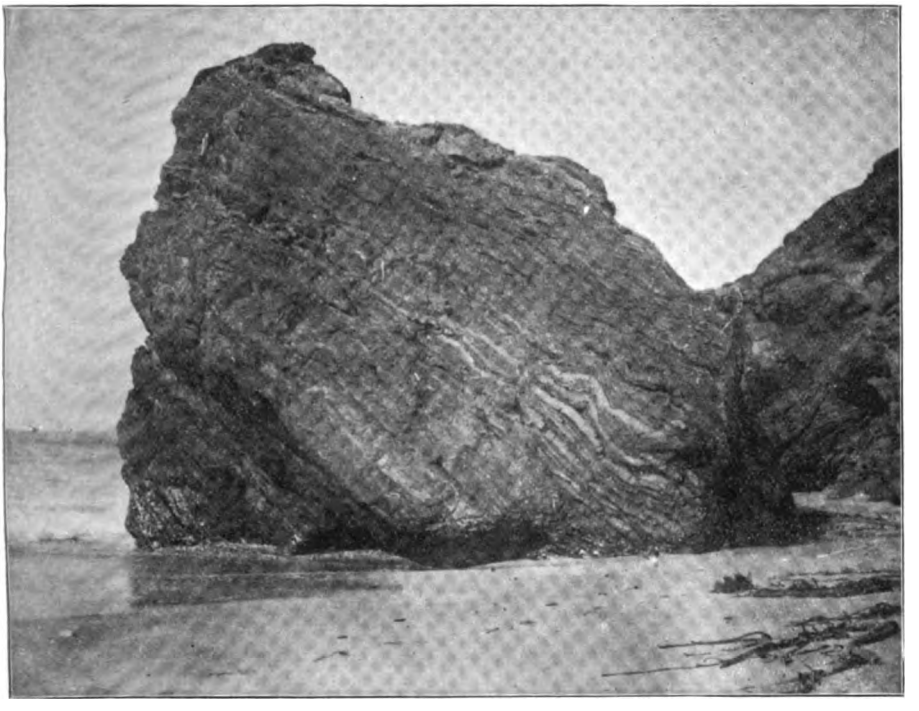

FIG. 1. Banded Jasper of the Golden Gate series, coast of Monterey county, California, near the mouth of the Sur River.

forms the larger part of the series wherever the writer has investigated it. The sandstone strata are often thick-bedded, which fact, taken together with the distortion undergone makes it very difficult to determine the bedding in small outcrops. Shale or slate occurs in subordinate amount, as thin layers between the sandstone strata, or more rarely in thick beds as in some portions of the Santa Lucia Mountains and the northern Coast Ranges.

Stratigraphic position.—The Golden Gate series as previously defined underlies unconformably the lowest known Cretaceous and rests on the crystalline basement rocks. It seems, for reasons to be mentioned, that no great lapse of time, geologically speaking, separated the deposition of the beds belonging to this series from the lowest Knoxville beds, but on the contrary the time interval separating it from the crystalline basement is very great. At numerous points along the coast of Monterey county this Golden Gate series rests on the granite and crystalline schists. For a distance of three or four miles in the vicinity of Slate's Springs it terminates below with a conglomerate which, on Hot Spring Creek, is 1000 feet thick.

The question of the relation between the Golden Gate series and the Knoxville is the all-important one. As far south as the fortieth parallel Mr. Diller has proved the existence of a series older than the Knoxville and separated from it by a nonconformity. Four miles east of Lower Lake the writer has observed an undoubted nonconformity between the *Aucella*-bearing shales and the older series. About Clear Lake the Chico rests unconformably on upturned masses of sandstone, jasper, and slate. In the Cañon of Capel Creek, Napa county, there are good evidences of a nonconformity between the Knoxville and an older series. In the Coast Range south of San Francisco the writer has observed the Chico at many points resting unconformably on a series of rocks lithologically very similar to that underlying the Knoxville farther north. The recent trip through the Santa Lucia Range resulted in the discovery of several distinct contacts between the *Aucella*-bearing Knoxville shales and an under-

lying series of jasper and sandstone. The most northerly known occurrence of the Knoxville beds in the Santa Lucia Range is on Pine Mountain opposite the town of San Simeon. The Knoxville beds here outcrop on the very summit of the range, being partly capped by liparite. They have an exposure of at least two miles from northwest to southeast and a width of a mile. The lower slopes of the mountain surrounding the beds consist of jasper, sandstone and dark, fine-grained eruptives. A section exposed along the grade of an old road crossing the mountain makes it very evident that the Knoxville overlies these rocks unconformably, but no good contacts were found there owing to the enormous amount of débris. On the southern slope the Knoxville beds are well exposed, dipping northerly at a gentle angle. To the east they are replaced by a ridge formed of hard sandstone and jasper, and in a little gulch eroded between these two formations, their relation to each other is distinctly shown. At one point the bottom and east side of the gulch consists of gray sandstone with thin, irregular layers of shale having a vertical dip and a north and south strike. On the west side the Knoxville shales, *Aucella*-bearing a few hundred feet above, appear in contact with the sandstone, dipping west at an angle of 40°. A short distance further up the gulch the Knoxville shales extend up to and overlie the gray sandstone with as marked a discordance in dip as that first noted. Less than one hundred feet away green jasper is interstratified with the sandstone.

Another area of the Knoxville beds occurs in the same range, north of the town of San Luis Obispo. The beds form much of the mountainous area extending from the railroad tunnel northwest for about fifteen miles. On the southwest these beds rest against a great serpentine ridge which forms one of the crests of the range. On the northeast they are underlaid by the sandstone and jasper of the Golden Gate series. At many points about the heads of Toro and Morro Creeks the Knoxville appears to have no great thickness, for it flanks the little hills and ridges of the Golden Gate series which project through it in the most

irregular manner. Numerous points were found where the contact was obscured by only a few feet of débris. The *Aucella* appeared widely distributed in the shales and sandstone, but its stratigraphic position could not be determined because of the complexity of the structure. On the summit of the range between Morro Creek and the Arroyo Atascadero a narrow arm of the Knoxville shales and sandstone is folded in vertically between ridges of the older series. The contact is plainly shown in the bed of a dry arroyo. Specimens of *Aucella* were obtained from a coarse sandstone blending into a conglomerate at a point which was apparently the lowest portion of the beds.

The Golden Gate series projects through the Knoxville in many places near the Eagle Ranch House. The former consists of jasper, sandstone and shale with large bodies of greenish, fine-grained eruptives. Absolute contacts showing an unconformable superposition of the Knoxville are rare because of the amount of soil everywhere present. More than a score of instances were noted where the contact between the two formations was hidden by only a slight amount of soil so that a few hours' work with a shovel would uncover it. The contacts already found, however, showing an unconformity, taken together with those where it is probable though not distinctly shown, and which would be accepted without hesitation by one thoroughly familiar with the two formations, establish on stratigraphic grounds the existence of an uncrystalline series below the Knoxville.

Faunal relations.—Fossil remains characteristic of a definite horizon have not yet been found in the Golden Gate series. This is a most remarkable fact when there is taken into consideration its extent, and the amount of study which has been given to it. The first fossil found in rocks which the writer would refer to this series is the *Inoceramus elliotti*, Gabb, from Alcatraz Island, obtained by Whitney. This was considered at the time as positive proof of the Cretaceous age of the San Francisco sandstone. In the summer of 1892 the writer obtained several poorly preserved specimens of *Inoceramus* from a bed of black

slate at Slate's Springs on the coast of Monterey county. This locality was revisited the past fall in company with Mr. Anderson, and a collection made embracing five species of lamellibranchs and a number of plants. The former though somewhat crushed were well enough preserved for generic determination. Unfortunately they proved to be very puzzling and threw but little light on the question at issue. They were submitted to Mr. T. W. Stanton for determination and the following description is given by him: "The collection includes a large species of *Inoceramus*, a large *Homomya* (?), *Macrodon*, *Leda* and *Rhynchonella*, none of which can now be referred to described species. The *Inoceramus* seems to me the most important form in determining the age, as it is confined to the Mesozoic, and a species of this size and type is probably not older than the Jurassic and might be Cretaceous. *Inoceramus quatsinoensis*, Whiteaves, from the *Aucella*-bearing Cretaceous beds of Vancouver is a similar species. Taking this in connection with the statements of yourself and Mr. Anderson concerning the field and stratigraphic relations of the beds, the most reasonable inference would seem to be Jurassic. The other fossils apparently do not conflict with this reference."

In the absence of confirmatory evidence the *Inoceramus* from Alcatraz Island cannot be accepted as proof of the Cretaceous age of the strata there, and it is very probable that the horizon represented is the same or nearly the same as that of the Slate's Springs beds.

The recent discovery of radiolaria in the jasper of the Golden Gate series not only adds greatly to the interest of these rocks but also may aid in the solution of the age problem. Those found by Mr. Ransome and Professor Lawson, and submitted to Mr. Hinde for examination, are, according to his description, forms similar to those occurring in the jasper of the Upper Jurassic and Lower Cretaceous of Europe. A part of the European beds containing the radiolaria are believed to belong to the upper Jurassic, while opinion is divided as to the exact horizon of the others. The specimens obtained by the writer

from the Eagle Ranch resemble those from Angel Island, but the number of species is greater and the state of preservation better in many cases. In Vol. XXXI. of the Palæontographica Rüst gives a plate on which are figured a group of radiolaria from the red jasper of west Switzerland which belongs to the upper division of the Jurassic. A comparison of the figures on this plate with those in a slide from the Eagle Ranch shows a remarkable similarity of the forms. At least five forms in the slide are closely allied to those on the plate.

It will be seen that as far as faunal evidence is concerned the question cannot yet be considered as satisfactorily settled. This much can be said, however, that the fossil remains found on the one hand in the jasper in different portions of the series, and in the slates near its base on the coast of Monterey, indicate with a strong degree of probability that the series as a whole is not older than the Jurassic and may belong to its upper division. Some of the forms, especially that of the *Inoceramus*, are very closely allied to known Cretaceous species, so that if palæontology alone had to be relied upon the question is at present a puzzling one. When, however, in addition to the faunal evidence, there is taken into account the fact of the unconformable position of the series beneath the Knoxville, the writer believes that its horizon can be stated with a considerable degree of certainty as Upper Jurassic. It may be best to add here that the application of the term Jurassic to this series is based on the fact that the Knoxville is at present considered by palæontologists as belonging to the Lowest Cretaceous. The writer does not wish to be understood as contending in this or in other articles previously published for a Jurassic series *per se*, but for the recognition of the existence of an uncrystalline series underlying the base of the Knoxville.

Stratigraphic position of the beds at Slate's Springs.—Lithologically the strata are entirely different from any portion of the known Cretaceous on the Pacific coast. They are considerably metamorphosed and in places extremely distorted and bronke. They stand nearly vertical and consist of alternating layers of

sandstone and slate. They are followed downward by a thick conglomerate, while other layers of similar conglomerate are exposed in the edge of the ocean. The whole series has an exposed thickness of 1500 feet from the base to the ocean cliffs, and extends an unknown distance beneath the sea. The slates and sandstones form a narrow belt, at times almost cut out by bodies of eruptive origin, for a number of miles down the coast. They gradually widen out to form the great area of pre-Knoxville rocks of the Santa Lucia Mountains in southern Monterey and northern San Luis Obispo counties. Four miles south of Slate's Springs and north of Big Cañon bodies of jasperoid rocks are associated with the sandstone. On the ridge south of Big Cañon are a number of outcrops of red jasper. At the mouth of Mill Creek is another body of jasper. Near the mouth of Vicente Creek slates outcrop along the cliffs facing the ocean, bearing the closest resemblance to those at Slate's Springs. A short distance south of Vicente Creek there are large outcrops of a banded red jasper. The Slate's Springs beds thus appear to be both stratigraphically and lithologically continuous with the Golden Gate series which on Pine Mountain underlies the Knoxville beds unconformably. Mr. Anderson, who has given considerable study to the Cretaceous of Oregon and northern California, agrees entirely with the writer with regard to the strongly marked lithological contrast between the strata at Slate's Springs and the Cretaceous, and their resemblance to portions of the Auriferous Slate series.

THE TIME INTERVAL BETWEEN THE KNOXVILLE AND THE GOLDEN GATE SERIES.

The great deformation exhibited by the Golden Gate series, its much higher degree of solidification and partial metamorphism, the numerous included bodies of eruptives formed prior to the deposition of the Knoxville, and the marked nonconformity between it and the Knoxville, all point to a time interval of considerable extent, during which there were violent disturbances terminating in its elevation and erosion. This interval may

represent a portion of the uppermost Jurassic or possibly the very base of the Cretaceous. Dr. White has represented graphically the position of the different divisions of the California Cretaceous in his Correlation papers. According to this the extreme basal portion of the Cretaceous is absent. The more recent work of Messrs. Diller and Stanton, which has been carried out with the greatest care, places the Knoxville at the base of the Cretaceous. This places the Golden Gate series in the Jurassic, and probably at a horizon which corresponds very closely with that represented by the Mariposa beds. Although the fauna at present known from the Golden Gate series is indeterminate in its time relations, as far as the Jurassic or Cretaceous is concerned, the pronounced nonconformity between it and the Knoxville must be taken into account. The interval necessary for the deformation, metamorphism and erosion of the lower series must have been considerable, and is to be correlated with that found by Mr. Diller to exist between the Upper Jurassic beds of northern and central California, and the Shasta-Chico series of the Sacramento Valley. The increasing mass of evidence is in favor of the views of Mr. Diller concerning the synchronism of the great revolution in the Sierras and the Klamath Mountains, which he holds took place near the termination of the Jurassic. Accepting this as true, as the writer has stated in former publications, a demonstration of the extension of this nonconformity southward also proves that the underlying rocks are at least as old as the Jurassic.

THE NONCONFORMITY BETWEEN THE CHICO AND KNOXVILLE IN THE SOUTHERN COAST RANGES.

In several papers the writer has expressed the opinion that there is evidence at many points in the Coast Ranges of the existence of a nonconformity between the Chico and Knoxville beds. This nonconformity is supposed to be due in part to a post-Knoxville elevation when numerous bodies of peridotitic eruptives were formed. As far as is known the Horsetown beds are absent from the Coast Ranges south of San Francisco. Until recently the Upper and Lower Cretaceous had not been

found together in that portion of the state, and their relation to each other was more or less a matter of inference. The contact which has just been found is on the Eagle Ranch in the Santa Lucia Range. The central portion of the range is there formed of Knoxville shales and sandstone carrying *Aucella*, the total width exposed being about three miles. The Knoxville is bordered on the west by a great dike of serpentine, while on the east a nearly hidden axis belonging to the Golden Gate series projects through it in numerous places. The Knoxville presents a very much disturbed condition, partly due to the dikes of serpentine. The Chico, consisting almost wholly of heavy-bedded sandstone, rises on the eastern slope, overlapping the Knoxville shales and capping portions of the first line of hills. It has not undergone the same amount of disturbance as the Knoxville and is nowhere folded in with it, appearing rather as a thin capping on an irregularly eroded surface. Fossils were sought for a long time in the sandstone without any result. Finally a number of poorly preserved specimens were obtained from the summit of a hill about one mile south of the Ranch House. The following is the list: *Baculites chicoensis*, Trask. *Trigonia evansana* (?), Meek. *Pectunculus veatchi*, Gabb, *Cucullaea sp.*, *Pentacrinus sp.* In a small ravine near the spot where the fossils were obtained there is a contact between the sandstone and the dark shales. This ravine extends up the west side of the hill making a slight depression nearly to its summit. The northern portion of the hill is capped with a thin layer of the Chico sandstone, dipping south at an angle of 30°. The sandstone extends to the bed of the ravine and is there exposed resting on the shales. The latter are well shown, not only underneath the sandstone but also on the slope of the hill south into which the dip of the sandstones would carry them. The sandstone has a very regular bedding while the shale underneath is so broken that the stratification is not distinctly visible. The spot was examined particularly with reference to the possibility of the phenomena being due to faulting, but no evidence of it could be discovered. Fossils were not found in the Knox-

ville near the sandstone, but at the base of the hill one-half mile distant, in strata which could be traced by continuous outcrop to the contact. On the north fork of the Atascadero, three miles northwest of this locality, is an *Aucella*-bearing stratum folded in between the older rocks. About 500 feet north of the vertical Knoxville shales is a hill capped with a body of Chico sandstone with only slightly inclined bedding planes. This hill lies directly in the strike of the shales, and although no contact is visible there can be no doubt of an unconformity.

THE RELATION OF THE SERPENTINE TO THE CHICO-KNOXVILLE UNCONFORMITY.

The absence of the Horsetown beds and the presence of numerous large bodies of serpentine favor the supposition of a break between the upper and lower divisions of the Cretaceous. Serpentine occurs intruding the Knoxville and older rocks at many points along the Santa Lucia Range. It seemed probable that such was the case on Pine Mountain although no good exposures were found. Near the Old Padre mine, west of Santa Margarita, the Knoxville shales in contact with the serpentine are considerably metamorphosed. On the Eagle Ranch a dike of serpentine has been cut on one of the grades, showing its intrusion in the Knoxville shales. The writer has never seen serpentine intruded in the Chico in any portion of the Coast Ranges, and all indications point to its formation during the interval between the deposition of the Knoxville beds and the Chico. In the southern Coast Ranges at least, the disturbance must have caused an elevation of the Knoxville, so that during the period represented by the deposition of the Horsetown beds in northern California, the former must have been above water and undergoing erosion.

THE NON-CONFORMITY BETWEEN THE MIOCENE AND THE CHICO-TEJON SERIES.

An examination of geological literature relating to the Coast Ranges shows that the Miocene has generally been held to have been deposited conformably on the Chico-Tejon series. This

question had not been studied in the southern Coast Ranges prior to the work done there by the writer. In that field numerous occurrences were noted where the Miocene unconformable overlaid the Chico, or Tejon, as the case might be. The non conformity was pronounced wherever contacts could be found, for a distance of 200 miles, through the counties of Ventura, Santa Barbara, San Luis Obispo, and Monterey. Topographically the southern portion of this region is very rugged and difficult of exploration. The deep cañons and brushy mountains rising 5000–7000 feet make access to it almost impossible except along the scattered trails. Geologically portions are quite complex but there are large areas where the Cretaceous, Lower and Middle Ter tiary are the only horizons represented. The assemblage of strata belonging to the Upper Cretaceous and the Lower Tertiary, known in geological literature as the Chico-Tejon series, is particularly prominent in northern Ventura and southern Santa Barbara counties. The Miocene not only forms complete mountain ranges, as for example, the Santa Ynez, but also appears as fringes along the Chico-Tejon elevations and in detached areas almost on their very summits. Beginning in northern Ventura county the various localities will be described where the relation of the Miocene to the Chico and Tejon was observed. Pine Mountain in northern Ventura county extends in an east and west direction between Cuyamas River on the north and the Sespe on the south. It forms the northern portion of a great thickness of dark shales and sandstones which have a width, north and south across their line of strike, of nearly twelve miles. Fossils were collected from two localities on this section, but so complex is the structure that the exact position in the series was not determined, although it seems that they are from the upper portion. On the northern slope of Pine Mountain the following fossils were collected: *Meretrix horni*, Gabb; *Fusus remondi*, Gabb; *Neverita globosa*, Gabb; *Dentalium pusillum*, Gabb; *Turris varicostata* (?), Gabb; *Actæonella oviformis* (?), Gabb; *Turritella sp.* The horizon indicated is the Tejon. Near the head of the Matillija Cañon, about eight miles southward, there was collected the

following Tejon forms: *Crassatella grandis*, Gabb; *Meretrix horni*, Gabb; *Cardium sp.; Fusus martinez*, Gabb; *Dentalium cooperi*. The Sespe in its upper course has eroded a broad longitudinal valley in the center of this formation. North of the stream on the southern slope of Pine Mountain is a body of heavy-bedded light yellow sandstone, dipping north generally at a small angle. Where the Matillija trail crosses it there were found numerous specimens of *Astrodapsis whitneyi*, Remond; fragments of *Ostrea titan*, Con., and *Pecten discus*, Con. Four miles down the cañon Dr. Bowers[1] has collected twenty-five Miocene species from the same sandstone. Although the actual contact was not observed, there can be no doubt as to the unconformity. The Tejon and possibly Chico strata below being steeply inclined and much broken, especially south of the Sespe, while the Miocene sandstone dips very regularly to the north into the Tejon, forming the summit and north slope of Pine Mountain. Near the mouth of Santa Barbara cañon there is a series of sandstones, gypsum-bearing clays, and limestones resting unconformably against dark thin-bedded sandstones and shales of undoubted Cretaceous age, although no fossils were found at this point. South of the Perkin's Ranch on the slopes of the Cuyamas Range are numerous areas of light yellow heavy-bedded sandstones resting on or against dark sandstones and shales. Specimens of a Miocene *Pecten* and *Ostrea* occur in the upper beds at different points. The following Chico fossils were found in the deep cañon of the Sisquoc, between the Cuyamas Range and the San Rafael Mountains: *Inoceramus, sp.; Meekia sella*, Gabb; *Pectunculus veatchi*, Gabb; *Cinulia obliqua*, Gabb; *Baculites chicoensis*, Trask; *Cylichna costata*, Gabb; *Tellina ashburneri*, Gabb; *Dentalium stramineum*, Gabb, and an unknown crustacean. The strata consisting of dark shales and thin-bedded sandstones are steeply tilted and much broken. Stratigraphically they seem to belong with the lowest beds in Santa Barbara Cañon. The uppermost beds at the head of the latter cañon occupy the highest position in a great synclinal fold, appearing to be a continuation of the Tejon on Pine Mountain. South of the Sisquoc,

[1] Report Cal. State Mining Bureau, p. 763.

capping the high mountains between it and the Manzana River, is a large area of light yellow sandstone, apparently not greatly disturbed. Continuing up the Sisquoc these sandstones were finally observed outcropping on the bank in direct contact with the Cretaceous. The discordance in dip of the two formations is about 15°. There does not seem to be any doubt about the reference of the sandstones to the Miocene, as they correspond exactly to the known Miocene only a short distance to the north. In the lower end of the Cuyamas valley are horizontal strata of incoherent sandstones bearing *Ostrea titan* and a species of *Pecten*, while only a short distance below are steeply inclined conglomerates and sandstones referable to the Chico.

In a small tributary cañon of the Santa Ynez River, below the old Mission, is a contact between a body of dark shales, closely simulating the Knoxville, and light yellow sandstone. The sandstone rests on the shales with a discordance in dip of 20°. In the shales no fossils were found, but in the sandstone two species were obtained: *Ostrea panzana* (?) Con., and *Pecten pabloensis* (?) Con. That portion of the Santa Lucia Range lying in southern San Luis Obispo county consists largely of heavy-bedded sandstones and conglomerates, which according to our present knowledge are wholly referable to the Chico. Near the head of the Santa Margarita Valley specimens of *Trigonia evansana*, Gabb, and *Axinea veatchi*, Gabb, were obtained from the sandstone. Five miles farther north several specimens of *Venus lenticularis*, Gabb, were found in a nodular mass of limestone in the same sandstones.

An excellent section of the Bituminous Slate series (Miocene) is shown for many miles along the Arroyo Grande which has its source in the Santa Lucia Range. Near its head in the vicinity of Music are extensive beds of sandstone carrying *Ostrea titan*, Con., and *Astrodapsis whitneyi*, Remond. Fully 2000 feet below this sandstone in the same series of rocks is a considerable thicknesss of soft argillaceous sandstone containing the following Miocene species: *Pectunculus patulus*, Con., *Leda cælata*, Hds., and *Arca microdonta*, Con. Between 200 and 300 feet below

these fossiliferous beds the Miocene terminates in a soft, white sandstone. This rock rests against nearly vertical beds of hard sandstone and shale which without much doubt are referable to the Chico, as they can be traced by continuous outcrop to localities where fossils of that age were found.

A narrow belt of Miocene shales extends diagonally across the Santa Lucia Range from a point west of Templeton to the head of Santa Rosa Creek. On the north fork of the Arroyo Atascadero this shale is filled with fish remains and the mollusk, *Pecten peckhami*, Gabb. The shales overlie rocks of the Golden Gate series and dip nearly vertically. Directly in line of their strike rises a hill of Chico sandstone, the bedding of which is nearly level. The Miocene can be traced by outcrop to within a few feet of the Chico; it was evidently deposited on the eroded surface of both the Golden Gate series and the Chico. The same white shales occur on the Eagle Ranch about three miles southeast of this point. There they dip about 30° southwestward apparently resting on the yellow Chico sandstones whose outcrop was obtained within 150 feet of the shales. The sandstone shows at many places a uniform dip of 20° to 30° to the northeast. West of the white shales is a hill of jasper partly capped by the Chico sandstone. The dip of the shales at the base of the hill is such that if extended they would pass beneath the two older formations. All the phenomena shown here point to the deposition of the Miocene on the eroded surface of the Chico.

CONCLUSION.

The correct determination of the age of the Golden Gate series is one of the most important questions in Coast Range geology. The accumulating evidences are strongly in favor of the view of its Upper Jurassic age. There can no longer be any doubt as to the unconformable position of the series beneath the Knoxville, and the fauna indicates that it is not older than the Jurassic.

If future detailed examinations should prove that the Horsetown beds are absent from the southern Coast Ranges, there

must be postulated a considerable period during the middle of the Cretaceous in which that region was elevated and undergoing erosion.

The Chico-Tejon has a thickness of at least 20,000 feet in several places. We have no knowledge at present of a stratigraphic break in the series, but the direct superposition of the Miocene on the Chico in many localities lends some degree of probability to the view that a break exists.

The Miocene exposed on the Arroyo Grande has a thickness of from 5000 to 8000 feet. The succession of strata from the top downward is as follows: (1) Bituminous slate, (2) Sandstone carrying *Ostrea titan*, (3) Bituminous slate and argillaceous sandstone.

In the vicinity of the Eagle Ranch there is one of the most interesting associations of strata of different age to be found in the Coast Ranges. Four formations are present from all of which fossils were obtained: The Miocene, Chico, Knoxville and Golden Gate series, each being separated from the others by a nonconformity.

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OSCILLATIONS OF THE COAST OF CALIFORNIA DURING THE PLIOCENE AND PLEISTOCENE.

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INTRODUCTION.

In the following paper it is proposed to trace out, as far as can be done at present, the character and sequence of the crustal movements along the coast of California during the later geological times. The investigation will deal particularly with those which took place during the Pliocene and Pleistocene. Various interpretations of the records left by these movements have been given by different observers, but their results do not harmonize with each other, nor does any one of them appear to express the whole truth.

The study was primarily suggested, partly by the views of professor Le Conte on a former elevation of the coast giving a land connection with the Santa Barbara islands, and partly by the results of the soundings of the United States Coast and Geodetic Survey as announced by professor George Davidson. The recent work upon the Pliocene and Pleistocene movements of the California coast by professor Lawson has resulted in conclusions radically different from those of professor Le Conte and it appears self evident that some one must entertain serious misconceptions.

In developing the subject from observation and study I have been led to the conviction that the later researches have failed to discriminate the different movements in a manner consistent with the actual facts open to observation. It will appear from what follows, that, concerning the important oscillations of the Pleistocene period at least, my conclusions are in accord with those of professor Le Conte.

In discussing the subject I will first give a brief outline of the generally accepted opinions of geologists upon the question in its broader aspects, and then in greater detail, the published results of study of that portion of the Pacific coast contained within the state of California where the most numerous observations have been made. Following this the main portion of the paper will be devoted more especially to a presentation of the leading lines of evidence relating to the epeirogenic as well as the orogenic disturbances of the coast region from the late Tertiary to the present. The special object will be to draw out the fact of an elevation of the coast much greater than the present during the earlier portion of the Pleistocene.

GENERAL MOVEMENTS OF PLIOCENE AND PLEISTOCENE TIME.

The more important events recognized in geology between the closing portion of the Pliocene and the present are believed by many to have been of almost world wide importance. Geikie* says: "The general succession of geological changes in post-Tertiary time appears to have been broadly the same all over the northern hemisphere." Dana's† discussion of this question is substantially as follows: (1) an elevating movement inaugurated near the close of the Pliocene and continuing into the Pletstocene, and terminating in the glacial period, (2) depression during the Champlain period with retreat of the glaciers, followed (3) in the Recent period by another upward movement, and last of all a possible subsidence. He inclines to the opinion that there are evidences of similar Pleistocene movements on the Pacific coast, basing his conclusions upon the terraces reported by geologists from that region, as well as on the presence of submarine valleys described by Davidson. These valleys extend down to depths varying from 2400 to 3000 feet and are considered by Dana as valleys of stream erosion, indicating an elevation of the coast of California of that much probably during the Glacial period. Dana farther quotes Dawson to the effect that an elevation of British Columbia of about 900 feet above the present existed during the Pliocene, that the fiords there occurring were enlarged during the following Glacial period.

*Text Book of Geology, 3d edition, p. 1050.

†Manuel of Geology, 4th edition.

An elevation above the present during the Glacial period is denied for much of the continent by some eminent geologists who believe that the events of that time were not so simple, yet, it seems to be admitted by all that a very considerable uplift was characteristic of the time immediately preceding glaciation, that during glaciation oscillations of level occurred, and at its close a depression, with an elevation in more modern times. Can the Pliocene movements of eastern North America be correlated with those on the Pacific coast occurring in the corresponding geological period? This is at present a doubtful question. The opinion seems to prevail that glaciation in the Sierra Nevadas was more recent than in the east. It is quite possible that with the general movements of higher latitudes there may have been independent orographic movements, or the epeirogenic changes may have partaken of the nature of a wave-like progression. It is certain that on the Pacific coast of the United States, and probably farther north, a subsidence was taking place during much of the time determined as Pliocene by professor Lawson, but whether this subsidence was synchronous with the upward movement of the Atlantic coast is not definitely known. Although it would appear from present knowledge that the two events were contemporaneous, yet there seems to be evidence that from the beginning of the Pleistocene to the present the important epeirogenic movements recognized in eastern North America have had their counterparts on the Pacific coast, although possibly not taking place on both sides of the continent simultaneously.

Earlier Opinions Concerning the Movements of the California Coast.

Professor Le Conte was the first geologist to call attention to the facts bearing upon a former elevation of the coast of California, although Mr. R. E. C. Stearns a number of years earlier, in speaking of the tooth of a fossil elephant which had been presented to the California Academy of Sciences said: "It proved that the island (Santa Rosa) was formerly a portion of the mainland." Professor Le Conte's views* are based

*Bull. Cal. Acad. of Sci., Vol. II, No. 8, p. 515.
American Geologist, Vol. I. p. 76.
Bull. Geol. Soc. of Am., Vol. II, p. 323.
Am. Jour. of Sci., Vol. 34, p. 457, 1887.

partly on the presence of submerged valleys off the coast, and partly on the peculiar flora as well as fossil remains of the Channel islands. During the elevation of the early Pleistocene Le Conte believes that the land stood at a hight of 2000 to 2500 feet above the present level. Then followed a depression the records of which are left in the raised beaches, and last of all an elevation to the position now occupied.

The late W. A. Goodyear* ridiculed the idea of the Santa Barbara islands ever having been connected with the mainland, saying that it was not certain that the elephant tooth presented to the Academy of Sciences ever came from Santa Rosa island. As a matter of fact however the beds of fossil bones occurring there have been described by both Voy and Yates and there cannot be the slightest doubt of their existence. A description of them will be given a little later.

Professor A. C. Lawson has devoted careful study to the Pliocene and Pleistocene movements of the coast of California but his conclusions are not in harmony with the earlier observations. The work of this investigator has extended along nearly the whole coast of the state, and as his results are important and have tended to shape recent opinion I will quote them at considerable length. Professor Lawson presents the following hypothesis† as the result of his studies at Carmelo. "The Pliocene corresponds to the more or less continuous depression of the coast, till the land was at least 800 feet lower than at present: – – –the Quaternary corresponds to the more or less continuous uplift which has affected the coast since the maximum depression was reached. – – –There is no evidence of an elevation of this part of the coast since Miocene times exceeding the present altitude." He does not consider the submarine valleys at Monterey and Carmelo bays as evidence of a former elevation.

In a more recent paper professor Lawson‡ concludes that there has been a recent uplift of 800-1500 feet between the Golden Gate and San Diego. He says farther: "A map of the shore at the beginning of the Pliocene would resemble the one of to-day. A map at the beginning of the Pleistocene would

*Report of the Calif. State Mining Bureau, 1889, p. 169.
†Bull. of the Dpt. of Geol., Univ. of Cal., Vol. I, pp. 57-58.
‡Bull. of the Dpt. of Geol., Univ. of Cal., Vol. I, pp. 157-159.

resemble rather that of the present Alaskan shore." The difficulty of drawing a line of division between the Pliocene and Pleistocene is then discussed and the conclusion reached that it can never be done on paleontological grounds, saying: "The reason for this is that there has been no distinct break in the continuity of marine conditions throughout the epochs, only a gradual transition of conditions. In this gradual transition there was however a reversal of the epeirogenic movement of the coast from a process of depression to a process of uplift. This turning point of the diastrophic pendulum, the intiation of the diastone of the epeirogenic pulsation is believed to correspond well with the beginning of the Pleistocene. – – The two epochs thus delimited have no interval of erosion between them and there will be found no marked break, except locally, in the sequence of marine life."

In another paper professor Lawson* distinguishes Pleistocene terraces to a hight of 1600 feet and possibly more, with the remnants of a Pliocene terrace formed during the deposition of the Wild-cat series. He recognizes three movements: (1) a depression during the Pliocene; (2) an orogenic movement at its close tilting the Wild-cat series; and (3) the general epeirogenic movement of the coast forming the terraces now so distinct. Speaking of the disturbances at the close of the Pliocene affecting portions of the coast he says: "These mountain-making movements were not however adequate to efface the peneplain (Pliocene), and the general altitude of the coast was not apparently affected." We have then at this time according to professor Lawson, the curious anomaly of of mountain-making movements not affecting the level of the coast.

The same investigator† has described a complex series of events which he supposes took place upon the peninsula of San Francisco during the Pleistocene. The region is believed to have sunken through the Pliocene permitting the deposition of the Merced series which is about one mile thick. "At the close of these orogenic movements (deformation of the Merced series) the altitude of the land was much lower relatively to the sea-level than at present. A general depression of the

*Bull. of the Dpt. of Geol., Univ. of Cal., Vol. I, p. 270.

†XVth Annual report of the U. S. Geol. Sur., p. 468.

land seems to have been concomitant with the more acute local disturbances or to have immediately followed them for we find marine terrace formations strewn over the region at an elevation of over 700 feet with a corresponding base-level plateau, and remnants of a still older plateau, also the result of baseleveling, at about 1100 to 1200 feet above sea-level." He goes on to say that from this general depression, excepting the last local sinking about the Golden Gate, elevation by stages has taken place from that time to the present.

The sequence of disturbances given on page 469 of the same report it is difficult to appreciate and is certainly open to question. They are as follows: formation of the San Bruno fault and the uplift of that range and the portion of the San Francisco peninsula lying to the north, resulting in the complete erosion of the Merced beds from the raised block; sinking of the San Bruno fault block; emergence of the San Bruno and Montara fault blocks together; development of terraces with the final emergence. The subsidence posited by professor Lawson as taking place at the time of the post-Pliocene disturbance or immediately following it is a most unique occurrence if true, but the phenomena properly interpreted are opposed to this view. A careful perusal of the report brings out the fact that the term "baselevel plateau" is used for a plain produced by wave action, and apparently does not mean anything more than a large wave-cut terrace. In this as in other papers he considers that in every case where the Pleistocene is found unconformable upon the Pliocene the truncation of the lower beds is always due to wave truncation. It does not appear possible that with a rising land and the accompanying terracing deposits several hundred feet in thickness could very often be formed upon the wave-cut floor.

In an earlier paper professor Lawson* expresses a different view from that quoted concerning Montara mountain, namely, that following the post-Pliocene disturbances it had undergone a period of subaerial erosion similar to that posited for the San Bruno mountains. The uplift however is assumed to have been merely local. The statement is as follows: "In the consideration of the diastrophism which has affected the San Francisco peninsula we have then, two displacements to deal

*Bull. of the Dpt. of Geol., Univ. of Cal., Vol. I, p. 149.

with, the orogenic or local, and the epeirogenic or general uplift. Is it possible to discriminate the two effects? Certain striking facts suggest an answer to this question in the affirmative. The orogenic uplift preceded the epeirogenic, and there was an interval between the movements in which a great denudation was affected." It will be evident from these quotations that it is exceedingly difficult to get at what professor Lawson's ideas really are on this question. His general meaning seems to be, aside from the discrepancies, that the post-Pliocene movements were purely of the nature of upthrusts of local fault blocks portions of which remained at or below the original level, and that the geography of the coast was not affected at all. The epeirogenic uplift referred to is that of the last uplift giving rise to the terraces. I cannot see what there is about the phenomena of these recent movements of the coast of California which makes it necessary to assume such peculiar mountain making disturbances, so different from the usual character of such events.

The views of professor Lawson in his different papers, although showing numerous contradictions, the earlier ones remaining unmodified in the later, may be generalized as follows. For the coast as a whole no marked disturbance appears to separate the Pliocene from the Pleistocene, a depression with transgression of the sea during the former, and a gradual re-elevation through the latter. Marked disturbances are recognized as having taken place locally, but without affecting any general elevation of the coast; while on the San Francisco peninsula a depression is recognized at the time of the disturbance or immediately following it. The San Bruno fault block is excepted, it having undergone a period of erosion before the deposition of the terrace formations. The history which professor Lawson thus recognizes as having been characteristic of San Bruno mountains I believe is characteristic of the whole coast.

Mr. George Ashley* clearly distinguished a period of land erosion between the formation of the Merced sesies and the Pleistocene terraces as the following quotation will show. "The arguments from the structural side are, that while, as shown by the fauna, this formation (Upper Merced beds) is

*Proc. Cal. Acad. Sci., Ser. 2, Vol. V, p. 334.

possibly later than the Pliocene, it is found to be overlaid by horizontal or nearly horizontal strata containing Elephas bones with evidences of a land period between. Since these beds were laid down, therefore, there has been a movement which has tilted them at an angle of 5-40 degrees followed by their being exposed to subaerial erosion, and later by being submerged and covered by deposits at one place over 200 feet thick, and then the whole subjected to a more or less general elevation to its present level. On page 352 of the same paper Mr. Ashley gives additional proof of the above statement.

DEMARKATION BETWEEN THE PLIOCENE AND PLEISTOCENE.

General Discussion. The Pliocene has been considered to have been closed in eastern North America by a marked elevation preceding glaciation. Lawson has already been quoted as to the condition of the California coast at this time. He has maintained that the coast was sinking through the Pliocene until 800-1500 feet below the present level. When this point had been reached a reversal took place, being preceded by local disturbances, gradually uplifting (epeirogenic movement) the coast to its present level. He considers the dividing line between the Pliocene and Pleistocene the point of greatest depression. Although I would explain differently the movements at the close of the Pliocene, considering them epeirogenic as well as orogenic, I think we must agree with professor Lawson that the point of change or disturbance forms a natural division between the two periods. This point is not an arbitrary one, not merely the reversal of an epeirogenic movement, as Lawson has said, but is marked by an important non-conformity. His statements have led Lindgren into a misconception of the actual condition of affairs in the Coast Ranges. Lindgren* says in a recent article: "It seems that in the maps of the valley border of the Sierra Nevada, the arbitrary line between the Neocene and the Pleistocene has been drawn considerably lower than the similar arbitrary line established by professor Lawson at the top of the Merced series. In other words the Pleistocene as defined in the gold belt maps occupies a considerably longer time than the Pleistocene on the coast as defined by professor Lawson. The Mer-

*Journal of Geology, Vol. IV, p. 905.

ced series is probably contemporaneous with the early Pleistocene of the valley border." It is evident that as yet we scarcely have information sufficient to permit a correlation of the movements in the Coast Ranges with those in the Sierra Nevada with any great degree of certainty. The recognized difficulty in delimiting the Miocene and Pliocene in the Sierras would perhaps be lessened if an attempt were made to take the clearly marked divisions in the Coast Ranges, due to more intense disturbances and changes of level, and see if a parallel could not be found for them in the Sierras, rather than vice versa. It is possible that the uppermost portions of the beds which have been termed Pliocene in the Coast Ranges could with equal propriety be included in the Pleistocene, which Lindgren as well as Ashley has suggested, yet the important stratigraphic break with the overlying Pleistocene makes a natural boundary which I do not think should be overlooked. The middle and lower portions of the Merced beds and Wild-cat series must be placed in the Pliocene if molluscan fauna are of any value in correlation. It seems, therefore, on stratigraphic grounds at least, that the limit of the Pliocene as determined by professor Lawson should be maintained.

Prof. Lawson* would correlate the Pleistocene elevation of the coast with the uplift of the Sierra Nevadas which followed the deposition of the auriferous gravels. It appears to me that these events have no relation to each other. The uplift of the Sierra Nevadas commenced before the close of the Pliocene as determined on the coast, at which time according to the researches of professor Lawson, the Coast Ranges were submerged. Lindgren says that the shore lines of the Sierras retreated westward during the Pliocene and if he correlates that time in the Sierras with any portion of the Pliocene on the coast, as he certainly must, there would appear to have been an upward movement of the Sierras with a downward one of the coast region. It is known definitely that in the earlier portion of the Pleistocene, as delimited on the coast, the Santa Barbara islands were connected with the mainland. The early Pleistocene of the coast would seem to correspond to the middle Pleistocene in the Sierras as given by Lindgren, and

*Bull. of the Dpt. of Geol. Vol. I, p. 158.

hence if glaciation was due to greater elevation, a contemporaneous upward movement was experienced by both at this time. The attempt at correlation may at the present be useless as it is exceedingly difficult to prove that even the epeirogenic movements affected the mountain axes alike. I think nevertheless that the best results are to be obtained by first clearly determining the limits of the Miocene, Pliocene and Pleistocene in the Coast Ranges, and taking the results as standards in the attempt to harmonize the nomenclature over the state.

Detailed Evidence from the Coast Ranges. It is rather difficult to determine the relation existing between the Pliocene and Pleistocene along the southern coast of San Diego county, although there are indications that the former has been somewhat disturbed and that the latter rests unconformably upon it. The highest terrace noticed by Lawson* in this region has an elevation of 800 feet. South of Poway valley however there are terraces of bedded gravel having an elevation of at least 1500 feet.

Between Oceanside and San Juan there is a stretch of mountainous country presenting some interesting features. Here occur very extensive beds of late Tertiary age, probably Pliocene, much disturbed and faulted and marked with Pleistocene terraces. The terrace deposits rest unconformably upon the slightly consolidated sands and conglomerates of this region. There is a distinctly marked baseleveled plateau of 2500 feet elevation forming a shoulder of the Santa Margarita mountains, but it may belong to a different epoch than the terraces. The San Onofre mountains have been raised by a fault which judging from the topography, cannot antedate the post-Pliocene disturbance.

Professor Lawson speaks of the Pliocene strata at San Pedro hill as being slightly deformed and truncated by wave action, and that on this surface the Pleistocene has been deposited. He says† further: "It follows that while there is a very profound physical break between the Miocene and Pliocene, the marine Pliocene and Pleistocene formations are very intimately associated with no epoch of subaerial denudation between them."

*Bull. of the Dpt. of Geol., Univ. of Cal., Vol. I, p. 120.

†Bull. Dpt. of Geol., Univ. of Cal., Vol. I. p. 128.

As in the case of the Pliocene of the northern coast an interpretation in favor of a period of subaerial erosion seems more reasonable. The very fact that the Pliocene has been disturbed and tilted is evidence which on its face would call for such a period of erosion.

Whitney* describes the Pliocene strata at Santa Barbara, which unconformably overlie the Miocene, as follows: "These strata themselves unconformable with the slates below are again overlaid unconformably by the recent or modern alluvial deposits."

Yates has described the Pleistocene strata of Santa Rosa island as overlying unconformably the slightly tilted Pliocene. This occurrence will be described at length in another place.

Both Whitney† and Lawson‡ mention the fact that the supposed Pliocene beds on the upper San Benito river have been faulted and tilted. The latter author§ also describes a slight tilting and faulting of the Pliocene beds at Carmelo. The description given is remarkably suggestive of the post-Pliocene disturbance and elevation which I have noted at other points

He speaks of the "older" and "newer" terrace deposits, the former being slightly tilted and faulted, and formed during the Pliocene submergence, the latter deposited during the re-elevation in the following Pleistocene. An unconformity is noted between the two in the sea cliffs and in the valley of the San Jose creek where a sheet of lava occurs separating two portions, the upper of which is less consolidated and without distinct bedding. The recent terraces are also described as having been cut in the older terrace deposits which are faulted into the carmeloite lavas. It seems to me clear from these descriptions that there is good evidence of an extensive disturbance and uplift accompanied with lava flows marking the line of division between the Pliocene and the more recent deposits. This disturbance was neither "local" nor is it possible to believe that the unconformity was marked by a period of wave erosion alone. The Wild-cat series (Pliocene) on the coast of northern California is described by professor Lawson as hav-

*General Geology of California, Vol. I, p. 134.
†General Geology of California, Vol. I, pp. 53-54.
‡Bull. Dpt. of Geol., Univ. of Calif., Vol. I, p. 153.
§Bull. Dpt. of Geol., Univ. of Calif., Vol. I, p. 56.

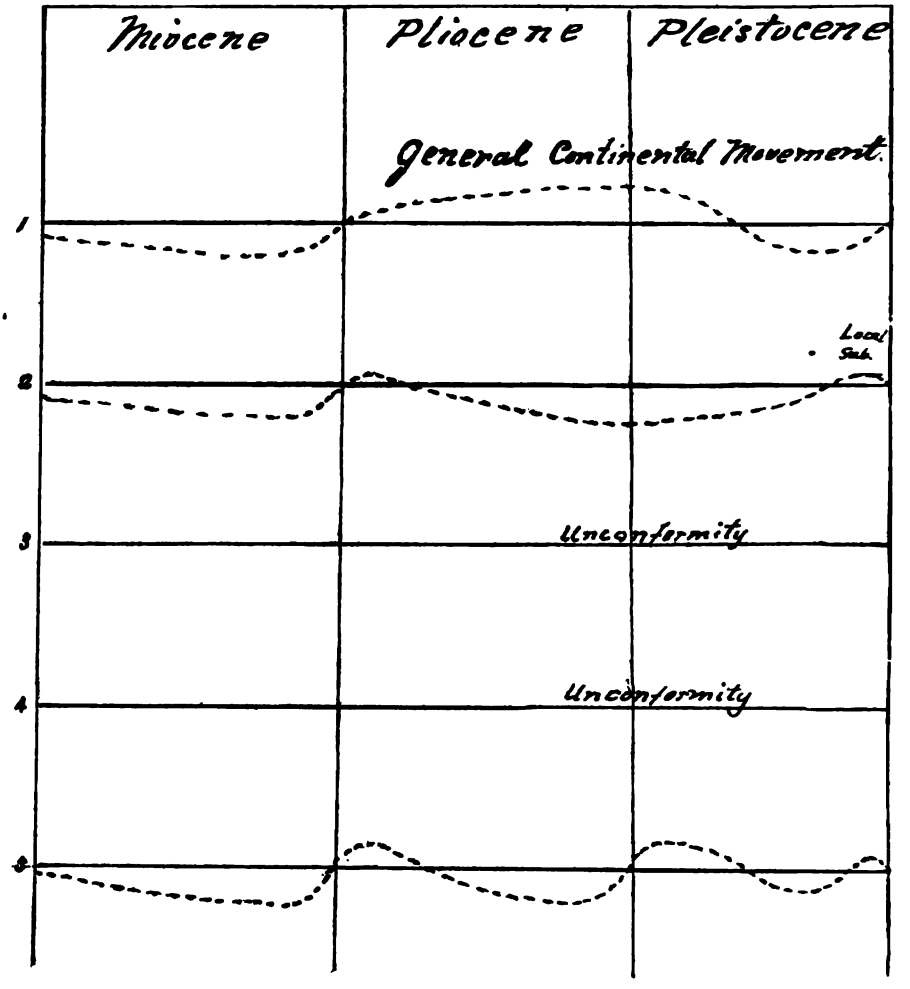
ing been affected by an orogenic disturbance which threw the Pliocene peneplain into "orographic blocks and anticlinal arches," but without any accompanying uplift. The evidence for no uplift will have to be made much stronger than it appears from the description given, before it can be used to offset the result of many lines of research all of which point to a very considerable uplift following the post-Pliocene disturbance the whole length of California. It is difficult to understand also how the Pliocene peneplain could have remained in a distinguishable condition after the beds of that age in the same region had been so generally deformed.

According to professor Lawson* the Pliocene is extensively developed in the hills back of Berkeley, east of San Francisco bay. The beds have been quite sharply folded and are briefly referred to in part as follows.† "The Pliocene rocks were all affected by sharp orogenic deformation prior to the general uplift of the coast." He mentions an "uplifted coastal peneplain" in these hills whose average elevation is about 1500 feet, but whether due to wave action or subaerial erosion is not stated. It is impossible to believe that in the Berkeley hills the post-Pliocene disturbance which so steeply tilted and faulted the Pliocene beds found there should not have elevated them above the sea and subjected them to a period of subaerial erosion before the depression took place in the recovery from which the terraces were formed.

Turner‡ has shown that mount Diablo was elevated at the close of the Pliocene and that the Pleistocene deposits lie unconformably upon the rocks of the former period.

Enough geological work has been done in the Coast Ranges to show that the post-Pliocene disturbances were not local but affected in varying degree the whole coast; that with this mountain-making process there was also associated a general uplift. The fact of a disturbance and elevation at the close of the Miocene is not questioned by any geologist and there is no valid reason for doubting that the similar phenomena marking the close of the Pliocene were due to similar causes. I cannot see anything in the nature of the phenomena present-

*Bull. Dpt. of Geol., Univ. of Calif., Vol. II, p. 94.
†Bull. Dpt. of Geol., Univ. of Calif., Vol. I, p. 268.
‡Bull. Geo., Soc. of Am., Vol. II, p. 402.



DIAGRAMMATIC REPRESENTATION OF THE VIEWS OF DIFFERENT GEOLOGISTS CONCERNING THE MOVEMENT OF THE CALIFORNIA COAST.

1. LE CONTE; 2. LAWSON; 3. TURNER; 4. ASHLEY; 5. FAIRBANKS.

ed to show that at the time of this latter disturbance these beds were folded beneath the sea, and that the erosion preceding the formation of the terraces was due solely to wave action, for wave action must have been carried on at the level of the sea, and after truncation, unless there was subsidence, there would have been no opportunity for the terrace formations, sometimes 100 to 300 feet thick, to have been left unmodified and unconformable upon the Pliocene, which as a matter of fact we find to be the case almost everywhere.

Post-Miocene Uplift.

There seems to be no question in the minds of geologists concerning the post-Miocene disturbance and uplift. By many it has been believed that the Coast Ranges originated at this time, but this, as I have shown in other papers, is clearly an erroneous conception, as the records of several stratigraphic breaks are visible in the older rocks of this region. It is very probable that the post-Jurassic disturbance elevated the coast so that the present islands were connected with the mainland and much of the submarine plateau exposed. As yet we know in only a general way the effects of the post-Miocene disturbance, but I believe that there are good reasons for assuming that the uplift was very marked and that the shore line was forced out some distance beyond the present one, probably taking in the submarine plateau. The Miocene is everywhere overlaid unconformably by the later formations. The valleys originating with the post-Miocene uplift, due partly to structural conditions, and partly to erosion, were more or less filled with sediments during the Pliocene submergence. With the early Pleistocene elevation they were again cut out, and filled during the following depression with the terrace deposits. As a result of this sequence it becomes difficult always to correctly discriminate and refer any particular phenomena of erosion to its true source. If we were in the possession of more records of deep borings in the mouths of the large valleys opening out upon the coast the question might more easily be settled. It is very evident however from the character of many of the larger valleys where the Pliocene reposes unconformably upon the Miocene that this relation extends below the present level of the sea. If this is the case these Miocene valleys are not simply of structural origin, and subsequently

filled with Pliocene and more recent deposits, but were excavated during the period of high altitude following the Miocene. The submarine valleys were then either originated or enlarged. There is good reason then for believing in several periods of high elevation in pre-Pleistocene times, a fact which makes it more difficult with present knowledge to distinguish the effects of the early Pleistocene elevation which it is the most particular object of this paper to demonstrate.

EVIDENCES OF A POST-PLIOCENE DISTURBANCE AND UPLIFT.

The Santa Barbara Islands. The evidence furnished by the vertebrate remains as well as by the flora of the Santa Barbara islands has been considered by professor Le Conte as abundant proof of an early Pleistocene elevation of the coast of California. The opposing opinion has strangely overlooked these facts in assuming a submergence at this time. Our knowledge of these islands is as yet very incomplete as far as the geology is concerned, but two observers have described the occurrence of the Elephas bones on the north side of Santa Rosa island. Dr. L. G. Yates* refers to the beds as follows. "On the north side of the island about 10 miles from the wharf, near the mouth of Soledad canon, we found an excellent exposure of strata consisting of about 90 feet of post-Pliocene deposits containing fossil bones of vertebrates, and at one place, fossil Physas (P. d'orbingniana) at a depth of some 75 feet below the surface.

This deposit is horizontal and overlies strata of older rocks probably Pliocene, which dip 13° N. E. and contain *Pecten*, *Turbinella caestrum*, and *Hinnites gigeantea* in abundance and in an excellent state of preservation. There is no indication of drift on Santa Rosa island, hence we cannot account for the presence of the fossil elephant on the theory of its having been brought by floating ice as advanced by some writers." He goes on to say that the chain of islands was formerly connected with the land to the east and that the Santa Barbara channel was a sound opening out to the west.

In an unpublished manuscript in the possession of the State Mining Bureau the late Mr. C. D. Voy describes the geology of Santa Rosa island in more detail. The older rocks of the is-

*AM. GEOL., vol. v, p. 51.

land appear to consist according to Mr. Voy of the Miocene and contain numerous characteristic fossils of that period. Above this is the great body of volcanic material. flow tuffs, etc. Mr. Voy's description is not clear in regard to the relative ages of the volcanic and Pliocene, but it would seem that the lavas, in part, at least, overlaid the Pliocene. The latter formation is widely distributed over the island and very fossiliferous. At various points along the bluffs on the northwest side the Pleistocene deposits appear 20 to 50 feet above the water and consist of clay and gravel. The Pleistocene also covers much of the island, overlying the volcanic. The bluffs are 100 to 200 feet high. and in the clay at various points, as well as in the little ravines on the surface, are numerous bones of the mammoth (E. primegenius), but all in an exceedingly poor state of preservation. Mr. Voy thinks there are two species represented. They occur 20 feet above the Pliocene and 100 feet below the surface. The specimens brought away are very fragmentary, but are to be seen in the Museum of the California State Mining Bureau. The first specimen from this locality, a tooth, was obtained by a Mr. Blunt in 1871.

Dr. Yates* gives a long list of Pliocene fossils from San Nicholas island. He also mentions the occurrence of pebbles of quartzite, porphyry and talcose rocks.. Similar ones are also found on Santa Rosa island. The pebbles in the recent formations on these islands indicate shallow water conditions. The Miocene sandstones and shallow water fauna also point to a land area in this region during that period. The fact that the Pliocene rests unconformably upon the older rocks shows the existence there of an interval of subaerial erosion similar to that following the Miocene upon the mainland. The islands were undoubtedly largely submerged during the Pliocene. Then an elevation took place with a tilting of the Pliocene and resulting erosion. The vertebrate remains occurring near the base of the Pleistocene point to the fact that the subsidence took place following the death of the animals. There seems to be every reason for correlating this depression with that recognized in the terrace deposits of the mainland.

The beds of mammoth bones is such conclusive proof of a

*IXth Report of the Cal. State Min. Bureau, p. 58.

former land connection that no question can be raised in regard to it. It might be supposed, however, that the islands were formed simply by a sinking of the region now occupied by the Santa Barbara channel. This view is not supported by the conditions existing since the early Pleistocene; no differential movements of such magnitude are known to have occurred. The recent downward movement has been general, affecting both mainland and islands. There are numerous facts, however, which point to the elevation of the coast as a whole, at the time when the mammoth flourished, which will be taken up in their proper place.

The deepest point on the submarine ridge connecting the Santa Barbara islands with the mainland is 125 fathoms or about 750 feet. This connecting ridge extends eastward toward Point Hueneme, near the mouth of the Santa Clara river. In all probability the post-Pliocene elevation was more than 1,000 feet. An elevation of 1,300 feet would connect the western-most of the islands with point Conception. The centre of the channel forms a depressed basin with a depth of about 2,100 feet.

The Submarine Plateau. The work of professor George Davidson* has shown that the coast of California, as well as of Oregon and Lower California, is bordered by a submarine bench or plateau of varying width. Along the coast of northern California it is quite narrow, being not much over 10 miles across. From Point Arena southward it begins to widen, sweeping just outside of the Farralones islands, and then narrowing again as the bay of Monterey is approached. Opposite the Golden Gate it has a width of about 32 miles. Off the coast of California the plateau of the Pacific has a depth which varies from 2,000 to 2,400 fathoms. The marginal plateau generally slopes very gradually out to the region of the 100 fathom curve, when it takes on the much steeper descent to deeper portions of the plateau or abyssal depths. Opposite the high and rugged Santa Lucia mountains the 100 fathom curve runs four to six miles from the shore, and from that the descent is rapid until a distance out of 57 miles, when it reaches a depth of 2,000 fathoms. Far-

*Hydrographic charts of the U. S. Coast and Geodetic Survey. Submerged Valleys of the Coast of California, Proc. Cal. Acad. of Sciences, 3rd series, vol. 1.

ther south, except off Pt. Conception, where it is only 35 miles across, the plateau widens greatly, sweeping outside of the Coast islands which lie off southern California, where a width of 150 miles is shown. The islands and shoals are dotted over this submerged region in a manner approximately corresponding to the direction of the adjacent mountains on the mainland. The slope outside the 100 fathom line along the southern coast is accentuated, but not so markedly so as farther north. The surface of the broad portion of the plateau is far from being uniform. Some of the islands rise over 2,000 feet above sea level, while the depths of the sea at their bases often reaches 600 fathoms. Southwest of San Diego about 35 miles there is the greatest depression in the plateau. Along the coast of Lower California the plateau narrows. How shallow portions of the plateau are, is shown by the fact that the 30 fathom line would include the larger of the Farralones islands lying 20 miles off the shore opposite the Golden Gate, while the 25 fathom line takes in the Coronados islands 12 miles off shore opposite San Diego.

The charts show a large number of submarine valleys opening from landward down across this plateau reaching a depth of from 100 to 500 or more fathoms. Where the plateau is narrow, as on the northern coast, they cut a trench completely across it. Where the width is greater off the coast of southern California the valleys open from the shore down merely to the deeper portions of the plateau itself. In several instances the valleys come very close to the shore, as at La Jolla, Newport, Hueneme, Monterey, and on the coast of Humboldt county. A most remarkable fact about these valleys is that they are generally nearly or quite at right angles to the shore line, and consequently to the broad structural features of the country. Professor Lawson's view that they are structural depressions seems utterly untenable in the light of this as well as other facts. An interesting feature of the plateau, especially that portion above the 100 fathom line is its very even surface. Across this surface the deep transverse valleys have been trenched. The submarine contours follow that of the shore line to varying depths, corresponding very closely sometimes down to 300 fathoms. Not only does the submarine surface present a smoothness in most marked con-

trast to much of the land adjoining, but what is more surprising, the valleys beneath the water do not in some cases seem to bear any relation to the topography of the land lying opposite. The most of the depressions do however appear to be related to corresponding depressions in the land toward which they head.

Now the question arises as to the manner in which this bench has been formed. Is it due to truncation or sedimentation or to structure? In its broad features I believe that we must hold it to be of structural origin, but nevertheless modified by both the other agencies. In general the width of the plateau bears very little relation to the important drainage features of the land, and even where at first sight there would appear to be a correspondence supporting the view that the plateau has been built up by sedimentation a closer examination shows that such is probably not the case. The plateau widens opposite the Golden Gate where the floods from the Great Valley sweep out into the ocean, but even here the outer edge of the bench is bordered by the Farralones islands which are formed of the ancient granites of the Coast Ranges. If the even surface is due partly to truncation and partly to sedimentation without any greater elevation than the present ever having been experienced it is most difficult to account for the transverse valleys. Faulting cannot possibly explain them. It seems to me that as first suggested by professor Le Conte, and in harmony with the other lines of evidence, the position and character of these valleys point to a former elevation of from 2000 to 3000 feet. It is true that the submarine valleys may have been originally cut out at the post-Miocene elevation, or even earlier, but the fact that they have not been filled and extend up so close to the shore in places points most conclusively to a comparatively recent elevation of the coast. How faulting without subaerial erosion could have produced the contours of the valleys as given by Davidson it is impossible to conceive, and when to this is added the fact that they do not conform as a general thing to the important structural features of the Coast Ranges we are compelled to seek a different explanation. In cases where a submarine valley comes up to the shore directly opposite the mouth of a land valley where the Pleistocene is at least hun-

dreds of feet deep it seems that the explanation can be sought only in a comparatively recent elevation of the coast. It must be borne in mind however that opposite the mouths of some of the larger streams no submarine valleys have yet been found. This fact might be accounted for by unusual local conditions during the epeirogenic movements. The soundings in places are also far from complete. A study of the nature of the bottom does not help us much. According to the charts sand extends down 40 to 75 fathoms. Rocky bottom is rarely found.

Beginning at the south I will mention briefly the important submarine valleys which the contour lines upon the charts show. A number of these valleys occur along the coast of Lower California, but will not be taken up. The first deep valley running in close to the shore is found at La Jolla, about 15 miles north of San Diego. It heads in a little bay just north of the town and opens out northwestward. The bay is bordered on the south by Chico sandstone, and on the north by the Tejon, while at its head there is a sandy beach one mile in length. Back of this lies a small valley extending into the Soledad hill, two miles distant. The mouth of the valley at least has been cut out on the northern limb of an anticlinal arch. No bedrock is exposed along the sandy stretch nor in the valley which gradually narrows toward the hills. The contour lines of the submerged valley sweep into the bay directly opposite the land valley, the 100 fathom curve being less than one mile out. The submarine valley is deep and narrow, extending down below the 300 fathom contour six to seven miles from shore. There must assuredly be some connection between this eroded land valley and what is apparently its prolongation beneath the sea. The evidence is conclusive that where the strip of beach occurs the land valley has at some time been eroded deeper than it is now and subsequently filled in. There is every reason to believe that the two valleys are really one and that the submarine prolongation was excavated by the same means as that on the land. The period of excavation is not indicated by anything observed here.

Following the coast northward no important trench appears until Newport is reached. Here opposite the mouth of the Santa Ana river is a narrow valley, not however extending below the 100 fathom contour. The country is low and marshy

along this part of the coast and it is impossible to believe that any structural conditions affecting the soft Pliocene and Pleistocene deposits could have formed a valley of this kind, and there can be no other explanation but that of a comparatively recent subsidence.

North of San Pedro hill near Redondo there is a long, deep and narrow valley extending up very near to the shore. Another valley but not so narrow occurs off Santa Monica. The Redondo valley extends easterly toward the very northern portion of San Pedro hill which according to Lawson consists at the base of Miocene shale dipping westward at an angle not to exceed 30 degrees. The northern and eastern sides of the hill consist of more recent formations. As the submarine valley extends east and west it is consequently not at all likely that it is of structural origin. Lying to the east back of both valleys is the broad Los Angeles plain of Pliocene and Pleistocene strata. It appears to extend beneath the sea forming a broad even slope down to the 100 fathom line.

The next broad land valley to the north is that of the Santa Clara river, which flows across Ventura county, with a general east and west course though bending toward the south near its mouth. Opposite nearly the middle of the broad alluvial bottom of this valley, though some miles south of the present mouth of the river, is another submarine valley reaching a depth of 300 fathoms and extending up very closely to the shore. Its direction is the same as that of the land valley on which it opens. As is the case with most of the submarine valleys this one is narrow and deep, and the question arises why is this so when the corresponding land valleys are often as in the present instance miles in width. If due to subaerial erosion their upper portions at least must have been cut out of the Pliocene deposits which filled the post-Miocene erosion valleys. Their narrow deep form would indicate that the post-Pliocene elevation was of a comparatively brief duration.

About six miles to the south of the valley described, and nearly opposite the present mouth of the Arroyo Las Posas, is another submarine valley of about the same size as the last and extending more nearly north and south. It reaches to a little greater depth than the last, but also extends up close to the shore, terminating near the west end of the lagoon at

the mouth of the arroyo. Both of these valleys are so situated with reference to the alluvial bottom that a structural origin does not appear possible.

The conditions at Santa Catalina island bear out exceedingly well the view of a former elevation. The submarine contours around the island have a curve very similar to that of the shore, indicating an extension of the main features of the topography to a depth of over 300 fathoms. The island is very steep, and rugged and the absence of terraces is no proof, as Lawson seems to think it is, that the island was never submerged. Mr. W. S. T. Smith* has recently shown that the land was submerged during the Miocene as much as 1400 feet below the present level and that in the recovery from the depression, at least one terrace was formed. He also expresses the opinion that in pre-Miocene times the island was elevated 2000 to 3000 feet above the present level. A recent subsidence is shown to have taken place amounting to about 350 feet. Thus many facts go to show that the history of the island in a general way corresponds to that of the mainland. The same thing is probably true of the Santa Barbara islands. The submarine contours about these islands from 100 to 300 fathoms down accord very well with the present shore contours.

At Carmelo bay, some distance northward, occur the next known submarine valleys extending close in to the shore. By Lawson they have been ascribed to faulting. He says:† "At Carmelo Bay there is no evidence of an elevation of this part of the coast since Miocene times exceeding the present altitude." There are two branches of the submarine valley occupying the bay, the larger and deeper of which lies to the south opposite the mouth of the San Jose creek. The valley of this stream extended seaward would accord exactly with the submarine depression.

The great valley extending east and west through the bay of Monterey reaches from near the mouth of the Salinas river down to an unknown depth, probably across the plateau to the abyssal depths of the ocean. This valley is also considered of structural origin by Lawson as the Miocene strata on

*Proc. Cal. Acad. of Sci. III Series, Vol., p. 69.

†Bull. Dpt. of Geol., Univ. of Calif., vol. I, p. 58.

both sides of the bay dip under it. The form of the depression does not however indicate a simple syncline, for the descent is gradual both on the north and south to the 100 fathom line below which it changes quite abruptly becoming very steep. The submarine valley proper on a section between Santa Cruz and Monterey is not over 4 miles wide, descending to 400 fathoms, while the main bay is 24 miles across. According to Lawson the sedimentary rocks dip westward at Pajaro, and taking in connection with this, the submerged northwest prolongation of Point Pinos, an east and west structural depression is rendered improbable. Granting that the broad features of Monterey bay are due to folded Miocene strata, that is are structural, the portion of the submarine trench extending up close to the shore near the mouth of the Salinas river must lie in strata more recent than the Miocene. In all probability the rocks of this age are much more than 1000 feet below the surface, which about the mouth of the river consists of Pleistocene and Pliocene strata. The Salinas well some distance back from the mouth of the river did not apparently reach through the Pleistocene at a depth of 1300 feet.

The recent subsidence at the Golden Gate forming a new outlet for the Great Valley accords very well with the absence of any marine valley at that point and supports the view of professor Le Conte that the outlet was at one time into the bay of Monterey.

Several submarine valleys* have been detected off the coast of northern California. These lie near together south of cape Mendocino and are quite remarkable in several ways. The distance between them is 8-10 miles and they cut across the submarine plateau at depths varying from 400 to 520 fathoms. Only one of them lies opposite a river's mouth, the coast generally rising very steeply to hights of 4000 feet a little over two miles from shore. The submarine valleys extend in remarkably close to the shore, one having a depth of 25 fathoms less than one third of a mile out. Another reaches to a point where the water is not more than 15 fathoms deep. They all lie very nearly perpendicularly to the coast line. The submerged plateau between them has a gentle and even slope down to the 100 fathom contour at a distance of 8 to 10 miles

*Proc. Cal. Acad. of Sci., 1886-1887.

from the land, where it begins to descend rapidly. While it does not seem that these valleys can be accounted for through structural conditions, the hypothesis of stream erosion does not at first sight appear well supported. However the fact that the mountains rise so ruggedly behind them to such hights, would, with increased elevation, result in the cutting of considerable canons across the plateau even if no large rivers debouched here. Their narrow deep character like those farther south would indicate a comparatively brief period of erosion.

Evidence from the Present River Valleys. Our knowledge of the submerged valleys is not complete enough at present so that we can decide certainly concerning earlier elevations from this source alone. But there is another line of research which t ken together with what has been presented leads irresistibly to the conclusion of the much greater elevation of the Pacific coast at several periods in the course of its history. This other question deals with the character of the present stream valleys where they debouche upon the coast. Nearly all the streams of the California coast are bordered by broad alluvial bottoms where they enter the ocean and for many miles back. They are not only at their baselevel of erosion but are actually flowing upon beds of unconsolidated sands and gravels of unknown depth. The bottom lands at the mouths of some of the rivers are 8 to 15 miles wide with no solid rock apparent anywhere except in the hills flanking them. What is the explanation of this fact? One of two solutions is possible, either they represent structural depressions which have been filled up to the present baselevel, or ancient valleys eroded during some former elevation and subsequently depressed and filled with sediments.

The main valleys of the Coast ranges generally follow the structural features and if they all did so the question could not be greatly elucidated by a study of them. There are however many exceptions to the rule, especially among the lesser valleys, some of the more important of which will be discussed. Perhaps the use of the term structural depression ought to be more fully explained. By it I mean a synclinal trough originated by folding, lying either below the sea or baselevel, and which has subsequently been filled by sedimentation.

Faulting as well as folding may determine the original courses of the main streams but be followed by extensive erosion if elevated above the ocean sufficiently. In the latter cases I would not consider the valley, for the purposes of this discussion at least, as of structural origin.

I will now enter upon a description of some of these valleys beginning at the south, and attempt to discriminate the phenomena of the post-Pliocene elevation from the others and also the indications of a very recent subsidence. The streams which flow westward to the ocean across San Diego county are baseleveled in their lower portions having cut sharply defined valleys across the mesa. Near the ocean they have broad alluvial bottoms the depth of which is not known. It must however in many cases be several hundred feet judging from the abrupt nature of the valley walls. The streams entering the ocean from the San Diego river southward to the Mexican line have not as far as known cut through the Pliocene to expose any older sedimentary rocks. The lower valley of the Tia Juana river is particularly broad and here the alluvium or Pleistocene is apparently very deep. The thickness of this deposit in the valley bottom is something less than an earlier Pleistocene elevation. How much less it is impossible to say for that elevation would have thrown the coast line nearly 12 miles to the west. There has taken place however a recent subsidence of moderate amount which complicates matters. In discussing the movements of the coast of southern California Lawson failed to recognize the fact of this subsidence, which is very marked at the mouths of many of the smaller streams. From Del Mar northward nearly all the valleys are flooded, the tide waters entering some of them a distance of nearly two miles, while the depressions of their mouths are often below level of low tide. The sea cliffs are also actively being eaten away. The streams about the bay of San Diego are not apparently flooded but it is quite possible that this bay as well as Falso bay has been formed by this very recent depression. The fact that we do not know just how much the recent subsidence has been makes it difficult to discriminate with certainty between the erosion of the early Pleistocene and that preceding this depression, but I think we are justified in assuming that the broad and flat baseleveled valleys with allu-

vial bottoms above the points of flooding were excavated out of the Pliocene or older strata, as the case may be, during an early Pleistocene elevation.

The plains of Los Angeles stretch from Newport north to Santa Monica broken chiefly by the San Pedro hills. The plains are underlaid by a very considerable thickness of Pliocene deposits, with Pleistocene on the surface. The submarine valleys at Newport, Redondo and Santa Monica must have been excavated chiefly in the Pliocene strata. The landward prolongation of these valleys was of course obliterated in the recovery from the Pleistocene depression. The mouths of nearly all the streams in this section, as along the coast of San Diego county, are more or less flooded. It is possible that the recent depression of about 350 feet which Mr. W. S. T. Smith recognized on Santa Catalina island is the same as that shown by the small submarine valley at Newport, opposite the mouth of the Santa Ana river, which is not apparent at the depth of 100 fathoms but extends very close to the shore.

The valley of the Santa Clara river has a general east and west direction curving toward the south near its mouth where the alluvial plain is many miles wide. The higher hills on either side are Miocene while the lower belong to the Pliocene. According to Mr. Watts* the valley is not a structural one but due to erosion. It is baseleveled for 30 miles from its mouth but the depth of the Pleistocene forming the bed on which it flows is not known. The submarine valley corresponding to this, as before remarked, comes very close to the shore. It must be in great part cut out of the Pliocene filling of the post-Miocene erosion valley. There is no reasons whatever for supposing that the deep and narrow valley could in any way be formed by the deformation of the Pliocene.

No more large streams are met until western Santa Barbara county is reached. Here the Santa Ynez and the Santa Maria enter the ocean with alluvial bottoms 10 and 5 miles wide respectively. No submarine valleys are known opposite these rivers. It is possible that with the last uplift the channels were filled pari passu with the emergence of the land. Both of these streams flow over sandy or gravelly beds for many miles back from their mouths. The Santa Ynez has a general course fol-

*Verbal communication.

lowing quite closely the post-Miocene folding of this region and we have no direct evidence yet as to the relative importance played by structure or erosion in its formation.

The Santa Maria has a very irregular course, much of its channel having been cut across the structural features of the mountains. The broad bottom of this valley extends back from the ocean for a distance of 20 miles with a grade of about 20 feet to the mile. At Fulger's point it issues from the Cuyamas canon, uniting at the same time with the Sisquoc. Both streams are baseleveled still many miles above the junction. This feature is particularly noticeable in the Santa Maria which has cut directly across the mountains through the Jurassic, Cretaceous and Miocene strata. The baseleveled condition extends into the canon for about 15 miles, the bed of the stream being quite broad but bordered by steep mountains, and the waters everywhere flowing over a sand bed. There can be no doubt that to stream erosion is due the broad lower portion of the Santa Maria valley as well as the upper portion. It has clearly been cut out of Miocene rocks at its upper end, as well as near its mouth, where, on the south side the Miocene rocks forming a part of Point Sal rise very abruptly and dip away. Through the most of the first 20 miles of its course the river is bordered by low hills which are in part of Pliocene age or even younger. The numerous wells 200 to 300 feet deep sunk in various parts of the broad valley have pierced layers of gravel, sand and clay which are apparently entirely undisturbed having a dip corresponding to the alluvial surface. These deposits are in all probability very deep and resemble in every character those of known Pleistocene age in the other large valleys of the state. We can thus distinguish here two periods of elevation, one following the Miocene, the other the Pliocene.

From Santa Maria north to Carmelo numerous streams have cut transverse valleys in the Coast Ranges but none of these have a very large watershed. San Luis Obispo, Morro, San Simeon and numerous other small creeks, as well as the arroyos La Cruz and Corpo Joro and the Sur river all clearly show at the points at which they enter the ocean indisputable evidences of a former elevation. The lower portions of all these streams flow over gravelly beds in alluvial bottoms

sometimes one half a mile wide. The very recent subsidence is shown by tidal lagoons at the mouths of many of these streams. This character appears most distinct with those streams which at present are not transporting much detritus. Morro bay has the character of a sunken area and probably dates from this last depression. The existence however of alluvial bottoms of very considerable depth above the extreme lower portions of the streams affected by the last subsidence must be taken as indicative of an earlier Pleistocene elevation. All the streams along this part of the coast have eroded their channels in Miocene or older strata unless it be with the exception of the Arroyo Grande which in its lower portion is bordered by more recent formations.

In the course of a geological study by the writer of the Buchon range west of San Luis Obispo some facts strikingly corroborative of a recent depression have recently been brought to light. It seems that in the case of two small creeks, their present valleys, eroded in the Miocene shales, extend beneath the ocean to a considerable distance. The mouth of one of these streams, Islay creek, where it enters the ocean between cliffs of shale has been filled up to base level with gravel, but soundings undertaken for the purpose of making a landing show an extension of the narrow land valley, to at least a distance where the water is seven or eight fathoms deep. It may extend further, but no effort has been made to trace it. The course of the submerged valley is beautifully shown during rough weather by the breakers on either hand. The slope of the bed of the creek back from the ocean appears to extend unbroken beneath the water, and this taken in connection with the fact that the cliffs are being rapidly eaten into and undermined leads to the conclusion that the subsidence is very recent.

Professor Lawson has interpreted the conditions at Carmelo bay as pointing definitely to the fact that the coast has never been elevated more than at present since the post-Miocene upheaval. To my mind the conditions lead to the opposite conclusion.

San Jose creek enters the ocean through a flat which certainly has been excavated at some time below the present ocean level, and the depression agrees in position with the ex-

tension landward of the deep submarine valley forming the southern side of Carmelo bay. I cannot conceive of the conditions under which a fault might occur which would give the bottom the character shown, without a period of subaerial erosion. The Carmelo river is spoken of by Lawson as base-leveled only in its lower stretches. On the contrary its broad sandy bed extends back 15 miles. Lawson holds also that because the mouth of the Carmelo river lies between granite outcrops not more than one-eighth of a mile apart the bedrock can be only a short distance below, and that consequently the elevation of the coast never could have been much greater. This conclusion does not necessarily follow for the bedrock may be much deeper than supposed, and besides there is another possibility. During the early Pleistocene elevation, and before the formation of the modern terraces the river may have emptied into the ocean north of Abalone point. The general character of the river bottom is most suggestive of a very considerable elevation during the early Pleistocene.

If professor Le Conte is correct in supposing that at one time the outlet of the great valley of California was into Monterey bay, ths size of the submerged valley at that point is easily accounted for. The Salinas river, however, is of no mean size, and during a portion of the year carries a large body of water. There can be no doubt whatever that at the mouth of this river the Miocene bedrock is at a great depth, and consequently the post-Miocene disturbance could not have been the origin of the submarine valley, as professor Lawson thinks. He* considers the Salinas valley to be a valley of erosion along a fault line and cut out in pre-Pliocene times. With the latter thought I am in accord, but that would necessarily demand that the pre-Pliocene elevation should have been much greater than the present, which conclusion is contrary to the opinion of the author just referred to. A deep well has been bored near the town of Salinas, which lies in the centre of the valley a few miles from the ocean. The material passed through is quite similar to that in some of the other large valleys, which is considered to be of Pleistocene age. With the Pliocene depression the valley must have been partly filled, and with the following early

*Bull. Dpt. of Geol. Univ. of Calif., Vol. I., p. 155.

Pleistocene elevation again excavated and in the recovery from the terrace period filled to the present level. The fact that the submarine valley extends close to the shore directly at the mouth of the present river makes it very certain that its upper portion must be excavated in the Pleistocene sediments and at a very recent epoch.

Indications of a recent subsidence are plainly visible near the mouth of the Pajaro river. A tidal lagoon extends northerly from a point west of Castroville for about ten miles. The lagoon is bordered by low hills of unconsolidated material, probably of Pleistocene age. The slopes of the hills facing the old channel show plainly the effects of erosion during a greater elevation, for it is inconceivable that it could have been excavated under present conditions.

Although the Pajaro river flows out to this ocean through a narrow canon on leaving the Santa Clara-San Benito valley, this fact cannot be used as an argument against the view that the Sacramento river once emptied here. The narrow and steep walled gorge has been cut very recently, possibly as a result of local warping. The hills immediately adjoining the canon on the south do not rise over 300 feet and are of recent formation.

The character of the broad valley north of San Pedro point is indicative not only of the recent subsidence which Lawson considers has affected the region about the bay of San Francisco, but of a very considerable elevation prior to the formation of the terraces.

From the foregoing considerations it is evident that the last depression has not been so local as Lawson has supposed. It is seen to have affected the most, if not the whole, of the southern coast. The negative evidence, according to Lawson, north of Bodega Head is not of great value, for the mountains generally come down quite abruptly to the coast. The flood plain described by him at the mouth of Eel river is strongly suggestive of a recent depression; at least I do not see any reason why the phenomena might not be interpreted as easily that way as any other. Lagoons occur at the mouths of Smith and Klamath rivers, but this region has not been studied.

A recent subsidence is plainly recognizable along the Ore-

gon coast according to Mr. Diller. He says:* "The last movement of the land by which the Oregon coast came to its present position was one of subsidence. This movement had a marked effect upon the rivers. They are drowned on the lower portions of their courses, and the tide comes far inland." The last subsidence is thus seen to have been a general one. There is no doubt that in certain places on the California coast, as at the Golden Gate, it is more pronounced and noticeable.

It might be argued from the character of the large valleys opening out through the Coast Ranges to the ocean that we have no definite means of discriminating the Pleistocene from the Pliocene, that the latter may be encountered only a slight distance below the surface, and that no reliable evidence can be gained from the study of this aspect of the supposed post-Pliocene elevation. Does the Pleistocene occupy a depression eroded out of the Pliocene which it is believed filled or partly filled the most of the older valleys of the Coast Ranges? It is admitted that much of the needed information is at present lacking, but there is nevertheless some of great value at hand. In the first place the Pliocene is found to be more or less tilted and faulted wherever it occurs, the Pleistocene on the contrary has simply been elevated in the epeirogenic movement of the coast without any other noticeable disturbance. From the Santa Ana plain on the south, to the region about San Francisco bay, wells possessing more or less of an artesian character have been found in the most of the larger valleys. The record of the material passed through in drilling these wells has been kept in many cases and it appears that it is generally quite uniform. It consists of unconsolidated gravels, sands and clays. Where fossils have been found, as in the Santa Clara valley and the Great valley, the strata are distinctly shown to be of Pleistocene age. Their position is somewhat basin-like and so entirely undisturbed that with some experience it can often be told quite definitely how deep certain strata lie in different parts of any particular valley. If the beds were of Pliocene age we know that this regularity would not be found to exist. I believe then that we have a right to extend our generalization from these valleys where fossils have

*17th Annual Report of the U. S. Geol. Sur., p. 50.

been found to others where we know the character of the strata but have no record of fossils. I think then that we can lay it down as a general fact that all the stream valleys opening out to the coast are filled to a very considerable depth with undisturbed deposits of Pleistocene age. In the plains of Santa Ana and Los Angeles artesian wells are found several hundred feet in depth passing through unconsolidated material. In the Santa Maria valley the wells reach down 200 to 300 feet passing through sands and gravel having the same almost level position as the surface of the valley. How much deeper this formation is we of course do not know. In the valleys of the Salinas and a few miles from the ocean is a well, reaching a depth of 1300 feet. The character of the strata passed through seems to be very similar to that shown by the deep wells of Stockton where they are believed to be of Pleistocene age. From Watsonville west to the ocean are artesian wells 70 to 256 feet deep lying in the flat bottom of the Pajaro valley. Numerous artesian wells have been put down the whole length of the Santa Clara valley and on both sides of the southern arm of San Francisco bay. They vary in depth according to position from 100 to 700 feet. Remains of Pleistocene mammals have been obtained in addition to marine and fresh water shells.

I think that in general there can be no doubt that these wells are confined to the undisturbed Pleistocene beds filling the earlier eroded valleys. The water coming down the present streams begins to percolate downward, as soon as the bedrock is passed, into the sand and gravels, the sedimentation lines of which conform to their original slightly sloping position, the position in which they were deposited during the greater elevation of the early Pleistocene. The beds of coarse sand, pebbles and sometimes boulders passed through in the Salinas well as in the Great Valley indicate that deposition followed close upon subsidence, and that a much greater elevation must have existed.

Conclusion.

It is believed that the above discussion has completely substantiated the view first advanced by professor Le Conte of a greater elevation of the coast during the early Pleistocene.

The difficulty of always being able to discriminate between the effects of the different movements is not overlooked, or the possibility of their being more complex than at present believed. It will be perceived that this view introduces another complete vibration, making two where professor Lawson has one, and appears in a general way to harmonize the movements on the Pacific coast with those recognized by many students in other portions of North America.

The marked orogenic disturbances which accompanied the epeirogenic movements at the close of what has been termed the Miocene, as well as those which have been considered as limiting the Pliocene in the Coast Ranges, should continue to be used as in the past to set off the rocks of these periods. These disturbances were accompanied by lava flows and resulted in marked nonconformities. The intensity of the orographic movements varied along the 800 miles of the California coast, and in the interior, so that owing to different conditions of life, as well as to this intensity, the number of extinct forms in the different beds, particularly in the Pliocene, show a considerable variation. The total outcome of the movements because of their local intensification has resulted in the elevation of Miocene strata over 6000 feet in portions of the Coast Ranges, while to the south near San Diego strata of that age are apparently absent.

It is believed that the various lines of evidence presented in regard to a supposed post-Pliocene uplift are incontrovertible, and that the disturbances recognized by all as occurring at that time could not have left the general level of the coast less than 1000 feet and probably much more than that, above the present, and that the upturned Pliocene beds were truncated by subaerial erosion previous to the terracing. This elevation must have been sufficient and perhaps much more than sufficient to permit of a connection of the Santa Barbara islands with the mainland. The movements of the islands also seem to have corresponded very closely with those of the mainland.

It is believed that the submarine valleys are in most cases if not in all explainable by no other hypothesis than that of subaerial erosion; that without doubt such valleys were formed following the post-Miocene uplift, or what is quite within the bounds of possibility earlier still, but that their final form,

aside from subsequent modification by sedimentation, was given them during the post-Pliocene elevation which the steep character of the valleys would appear to indicate was of no great duration geologically speaking. The lack sometimes of correspondence between these submarine valleys and those of the present streams may be due in part to changes in the land topography and in part to local conditions during the rising and sinking.

The more important movements of the coast during the time under discussion are believed to have been as follows.

(1) Post-Miocene disturbance, resulting in an elevation much greater than the present, and outlining during the resulting erosion many of the present land features and originating or enlarging some of the marine valleys.

(2) Pliocene depression and accompanying sedimentation in favored localities.

(3) Post-Pliocene disturbance accompanied with folding, faulting and upheaval to a greater elevation than the present; a movement probably felt in the Sierra Nevadas and resulting finally in the glaciation of that region. During the erosion of this early Pleistocene the existing valleys of the Coast region were wholly or partly re-excavated in conjunction with the present marine ones. During the period of elevation, probably not later than the middle Pleistocene, the mammoth and other extinct mammals occupied the Pacific coast and spread over what are now known as the Santa Barbara islands.

(4) After a comparatively brief period as shown by the steepness of the submerged valleys a downward movement began and continued until the land was at 1200 to 1500 feet below the present.

(5) In the recovery from this sunken condition the terraces were formed and an elevation reached which was somewhat greater than that now shown.

(6) Last of all took place the subsidence recognized by Mr. Diller in Oregon, by professor Lawson at the Golden Gate and by the writer along the coast to the south.

A present discussion of this subject must be far from exhaustive and future study may bring out modifications of the above outline, but it is hoped that some permanent addition has been made to the knowledge of the history of this region.

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GEOLOGY OF A PORTION OF THE SOUTHERN COAST RANGES.[1]

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INTRODUCTION.

IT is the intention to present in the following paper a résumé of the most important results obtained during a detailed study of a portion of the southern Coast Ranges of California.

The area embraces about 570 square miles in the western part of San Luis Obispo county with the town of the same name nearly in the center. It has a length from north to south of thirty-five miles and an extreme width from east to west of

[1] Published by permission of the director of the United States Geological Survey.

twenty-nine miles. The seacoast traverses it diagonally forming the southwest boundary. The region is one of complex structural features and has represented within it nearly all the sedimentary formations characteristic of the Coast Ranges as well as a great variety of igneous rocks. As far as the writer has yet studied the Coast Ranges no other region of equal area has been found to contain so much of geologic interest.

More than six months of the past year has been devoted to field work[1] in this region besides several reconnoissances in former years. It is expected that a part of the results will appear in the form of a folio of the United States Geological Survey, and a complete report later in one of the Annuals.

TOPOGRAPHIC FEATURES.

The main topographic features have a northwesterly and southeasterly direction. The Santa Lucia is the highest and most important mountain range, extending parallel with the coast across the center of the area surveyed. On the south forming the high ridge terminating on the ocean in Point Buchon is the San Luis range. Crossing the northeast corner of the area is the northern extension of the San Jose range. All three ranges are traversed by narrow canyons which open upon broad and almost level or undulating valleys which extend in a northwest and southeast direction between these three important mountain blocks. The area is thus divided into two portions with sharply contrasted cycles of development, that is, recent mountain ranges with steep slopes and traversed by narrow canyons, and broad valleys in an advanced stage of base-leveling.

The Santa Lucia range forms the divide between those streams which flow directly into the Pacific Ocean and those which drain into the Salinas River. The valley of the upper portion of this river crosses the region surveyed between the

[1] The writer was aided in the field by Mr. F. E. Harvey, a senior student in Stanford University, and Mr. Robert Moran of San Luis Obispo, both enthusiastic students.

Santa Lucia and San Jose ranges. South of the Santa Lucia, between it and the San Luis range, are the broad and fertile San Luis and Los Osos valleys opening northwestward to Morro Bay. A series of sharp peaks extends from a point a little south of the town of San Luis Obispo northwest to Morro Rock separating these valleys from the foothills of the Santa Lucia range.

The Santa Lucia range as far as its recent movements are concerned forms a geological unit, and viewed from the south it presents a bold and comparatively regular front and even sky line. The highest portion has an elevation of nearly 3000 feet, and the summit a width of two to four miles. The topography of this range while presenting certain common features yet varies greatly in different portions, owing to the marked variation in resistency offered to erosion by the different geological formations. The Monteveys hales, which are mostly confined to that portion east of Cuesta Pass, are cut by deep V-shaped canyons while northwest of this pass the soft Knoxville shales, extending longitudinally through the centre of the range, exhibit a succession of open valleys.

The granite mountains (San Jose range) in the northeastern corner of the area surveyed reach an elevation of nearly 2000 feet, but do not seem so high because of the elevated valleys about them. They are cut by narrow canyons, but do not rise as abruptly from the adjoining valleys as the Santa Lucia range. This elevation of land is a magnificent example of an ancient base leveled mountain range. Viewed from most any point along the foothills of the Santa Lucia range the numerous furrowed ridges fall into an even sky line many miles long.

The San Luis range attains an elevation of a little over 1800 feet. It consists of a series of sharp ridges traversed by deep narrow canyons. To the east it lessens in height and finally blends with the Santa Lucia range.

The line of buttes extending from the vicinity of San Luis Obispo northwestward and terminating in Morro Rock constitutes the most remarkable scenic feature in the landscape. The buttes

rise from 400 to 1500 feet from open valleys which are but little elevated above tide level, and terminate in Morro Rock which rises out of the ocean to a height of nearly 600 feet. These are undoubtedly peaks of erosion, the hard crystalline rock of which they are composed weathering away much more slowly than the soft strata of the Golden Gate series in which they were intruded.

The extensive valleys south of the Santa Lucia range are underlaid by the oldest sedimentary rocks (Golden Gate series) of the sheet and are, in their general features, of great antiquity compared with the abrupt mountain ranges on either hand. The valley block has acted practically as a unit since the period of disturbance giving rise to the Santa Lucia and Buchon ranges.

The principal hydrographic basin is that of the Salinas. This stream flowing across the northeast corner of the area pursues a comparatively regular course until it empties into Monterey Bay. The remarkable thing, however, about the river is, that instead of flowing in the lowest depression between the Santa Lucia range and the granite mountains, it has cut a channel for a number of miles through the granite flowing in a canyon 500 to 700 feet deep.[1] Its meandering course brings it in places to the edge of the granite, where it receives tributary streams from the Santa Lucia. These transverse streams have so eroded their separating divides in the soft sandstones between the two ranges that they form an almost continuous valley which is strictly a continuation of the valley of the Salinas farther down. This is clearly a case of superimposed drainage, for when the course of the Salinas and its tributaries was originally outlined the present valley region must have been higher than the granite ridge.

A similar superimposed drainage is to be observed in the case of the streams which flow southwesterly from the Santa Lucia range. These traverse the broad open stretches of the San Luis valley, which in its lower portion is not over 200 feet

[1] JOUR. GEOL., Vol. V, p. 576.

above the sea, and separated from Los Osos valley by a divide not 50 feet high, and then pass directly into the San Luis range, cutting across it in narrow canyons at right angles to its course for a distance of over three miles. The most westerly of these streams, the San Luis Creek, has cut through where the range is 1000 feet high; and the other, Pismo Creek, traverses it where it is but little lower. The watershed between these streams has almost disappeared, and but little change in the topography would cause the whole drainage to pass westward along the northern slope of the San Luis range to Morro Bay. When the courses of these streams were originally outlined the San Luis range probably did not exist, and the general slope of the country was southwesterly. With the beginning of the upward movement along the axis of the range erosion continued to be rapid enough so that the original drainage was maintained.

SEDIMENTARY TERRANES.

An almost continuous series of sediments from the Middle Mesozoic down to the present is represented in different portions of the central and southern Coast Ranges, but owing to the oft repeated mountain-making disturbances the series is not complete at any one spot. Except for the absence of the Horsetown beds, the Eocene, and possibly the marine Pliocene, the series is practically complete in the region under discussion.

In the northern portion of the Santa Lucia range and other portions of the Coast Ranges there is still an older series of sedimentary rocks which are of unknown age, but were involved in the granite magma at the time of its formation and now appear as marbles, schists, etc. All that is known about these rocks is that they are older than the granite, and that the granite itself is much older than the Golden Gate series (Jurassic) which rests upon it with a basal conglomerate. None of these metamorphic rocks appear associated with the granite north of the upper Salinas River, although farther northwest along the same crystalline axis they are extensively developed.

JURASSIC PERIOD.

Golden Gate series. — This series forms the base of the unaltered sedimentary rocks in the central and southern Coast Ranges. The exact position of these rocks in the geologic scale remained a puzzle to geologists for many years, partly because of the scarcity of fossils, and partly because of the obscure stratigraphic relations.

In former papers[1] the writer has advanced considerations for the belief in the pre-Cretaceous age of this series of rocks, and that it underlies the Knoxville unconformably. In later papers[2] the series was named and more definite proofs given of its relation to the Knoxville. During the recent detailed study of the region about San Luis Obispo the question was conclusively settled in favor of the position maintained by the writer. Two lines of evidence aided in the determination. The first concerns the relation of the series to the Knoxville. Both of these groups of rocks are extensively developed in the region in question, each with its characteristic features. The Golden Gate series is most largely exposed along the southern slope of the Santa Lucia range, in the large valleys at its base, and on the northern slope of the San Luis range. A narrow strip also occurs on the northern side of the Santa Lucia range, exposed through faulting. The Knoxville beds begin as scattered outcrops on the southern slope of the Santa Lucia range east of the town of San Luis Obispo and extending northwest through the depression in the range known as Cuesta Pass, expand to form many square miles of mountainous country through the heart of the range. At numerous points on the northern slope of the range, from the Eagle Ranch to the head of Morro Creek, were found patches of the basal Knoxville conglomerate, either resting upon the upturned Golden Gate series, or upturned itself and faulted down into the latter series. Specimens of Aucella were found in strata of sandstone and fine conglomerate within four feet of

[1] Am. Geol., Vol. IX, p. 153; Am. Geol., Vol. XI, p. 70; Bull. Geol. Soc. Am., Vol. VI, p. 71.

[2] Jour. Geol., Vol. III, p. 415; Am. Geol., Vol. XVIII, p. 350.

the base of the beds. Near the road, two miles northeast of San Louis Obispo, the base of the Knoxville beds is exposed on a little hill. It consists of conglomerate, perhaps thirty feet thick, and dips easterly at a low angle. Exposed on either side of the hill and passing through under the conglomerate is one of the pre-Cretaceous basic intrusives similar to others near by in the Golden Gate series. This must have been the old sea bottom on which the conglomerate was deposited. In Reservoir Canyon, a little more than a mile southeast of this locality, is a hill about one-half mile in diameter formed of Knoxville shales and one thin layer of conglomerate. The shales are but little inclined and are underlaid and surrounded on all sides by the upturned and nearly vertical sandstones and associated intrusives of the Golden Gate series. Perfectly preserved specimens of *Aucella* were obtained from a concretionary nodule at the very base of the Knoxville on the south side of the hill.

The second line of evidence, that of palæontology, leads to the conclusion that the series is not older than the Jurassic, the radiolaria as well as the molluscan remains both agreeing upon this point. All the specimens of the latter so far obtained from the series are probably new species and appear to be indeterminate as far as the question of Jurassic or Cretaceous age is concerned. Only one locality of mulluscan fossils was discovered and that is located on the coast, six miles north of Port Harford. A small species of a pecten-like form occurs in great abundance here through a thickness of about eighty feet of black slate which stands vertical and is inclosed between dikes of diabase.

The strata of the Golden Gate series consist of sandstone which forms fully four-fifths of the whole, numerous lenticular beds of radiolarian jasper, shale, and a little conglomerate. The whole has been upturned, folded, and faulted in a very complex manner and intruded at various periods by dikes of igneous rocks in great variety and abundance. The different members of this series have the same character as in other portions of the Coast Ranges where they have been described.[1]

[1] Bull. Geol. Soc. of Am., Vol. VI, p. 82; U. S. Geol. Sur., XVth Annual Report, p. 415.

The sandstone is characteristically thick bedded and in general shows little if any metamorphism, except in the vicinity of eruptive masses. It disintegrates readily, forming a rather heavy soil. It is almost everywhere, however, seamed and fissured, while the softer, shaly strata are often crushed and distorted. The five-mile section along the coast, north of Port Harford, exhibits the relative proportion of sandstone in the series. Along this stretch the strata stand vertical and with the exception of thin layers of shale and several lenticular strata of jasper consists entirely of sandstone. The apparent thickness of this section is fully 10,000 feet, but whether this represents the total thickness of the Golden Gate series is not certain.

The outcrops of jasper are very abundant over the whole of the region occupied by the Golden Gate series, and as they weather away much more slowly than the sandstones form the most prominent of the smaller topographic features, rising often as jagged or rounded knobs above the rolling contour of the hills. There are at least half a dozen important horizons, which, though apparently not confined to any one portion of the series yet are mostly aggregated toward what seems to be the basal portion. The strata of jasper are of very irregular dimensions swelling and pinching and often appearing as isolated lenses, but rarely exceeding 100 feet in thickness. The basic intrusives so numerous in the Golden Gate series occur mostly in that portion occupied by the jasper beds, the latter generally being reddened and often involved in the erupted masses. The contact of the jasper with the sandstone as well as the easy parting of the jasper bands undoubtedly facilitated the passage of the molten matter. The organic nature of the rock is indicated by the minute radiolarian skeletons in which the structure can often be seen with a pocket lense.

Scattered over the area occupied by the Golden Gate series occur prominent outcrops of a metamorphic schistose rock having a predominantly bluish tint. Owing to the general covering of soil the relations of these rocks are not always shown but where exposures are sufficiently good they appear to

be bunch-like or eliptical in form, sometimes 100 feet thick and several hundred feet long, and from this size down to those only a few inches in thickness. Where the inclosing rocks are exposed they invariably lie in contact with one of the fine grained basaltic intrusives. Glaucophane gives the characteristic bluish tint, but other minerals, such as a pearly mica, chlorite, quartz and garnet occur. These rocks possess great interest though the problems connected with their occurrence are not yet all solved. There can be little question that they have been formed through the metamorphosis of argillaceous strata in contact with igneous masses, but why this action was so irregular and intermittant it is difficult to comprehend. It is also puzzling to know why the contact rocks are invariably associated with a certain type of the pre-Cretaceous basic intrusives and not with others, such as the peridotites. The exceeding abundance of the contact rocks through those areas of the Golden Gate series where the old eruptives are the most numerous, indicates plainly that the most if not all the latter are of subsequent origin.

CRETACEOUS PERIOD.

Knoxville Beds.—The rocks of lower Cretaceous age are now confined to the Santa Lucia range, although once probably much more extensive. They form an almost continuous strip from the head of the Corral de Piedra Creek on the south slope of the Santa Lucia range northwest for a distance of over twenty miles. North of Cuesta Pass they widen out forming for a number ot miles nearly the whole of the brush-covered mountains between the two crests of the range. The structure of this portion is synclinal and seems to be due to the intrusion of great masses of diabase along its edges and which form the double crests referred to. The beds are perhaps 3000 feet thick and consist of dark shales and thin bedded sandstones closely resembling those of the same age in other parts of the state. Several thin layers of pebbly conglomerate occur, one being at the base and containing numerous pebbles of jasper and other silicious rocks.

The genus *Aucella* is well represented through the lower and middle portion of the shales, but the upper portion appears to be barren of life.

The nonconformity with the underlying Golden Gate series is most marked, not only by the discordance in dip but through much less distortion of the upper beds and the entire absence of the intrusives so characteristic of the lower series. Although so much evidence exists of a break between these two groups of rocks, its real magnitude does not yet seem to be appreciated by geologists as it ought. The more the question is studied the more its importance must appeal to geologists.

Chico formation.— The upper portion of the Shasta group known as the Horsetown beds was not recognized within the area under discussion and it seems probable from the stratigraphic relations existing between the Knoxville beds and the Chico formation that it is absent. The Chico occurs in two widely separated localities. The most important one forms a belt one to two miles wide and many miles long on the northern slope of the Santa Lucia range. The other is a strip about the same width extending along the coast from a point six miles west of Cayucos, northwestward for about eighteen miles. In both areas the rock consists almost wholly of sandstone. Fossils are not abundant but they were found in sufficient numbers in the Santa Lucia Mountains to demonstrate the age of the formation. In the latter locality the sandstone terminates downward in a conglomerate which is in places 100 feet thick, resting either upon the Knoxville shales or the Golden Gate series. The sandstones on the coast rest upon the Golden Gate series exclusively. The relation to the Knoxville shales was carefully examined at many points along the northern slope of the Santa Lucia Mountains and a conclusion reached which is in accord with one already published,[1] namely, that the lower and upper Cretaceous are, in this region at least, separated by a nonconformity. This is shown by the marked discordance in the dip between the two and the extension of the upper across the

[1] JOUR. GEOL., Vol. III, p. 426.

strike of the lower, as well as by the fact that the upper rests indiscriminately upon either the lower Cretaceous or the Golden Gate series. A nonconformity is also indicated by the fact that where the serpentine in this region, as in other portions of the Coast Ranges, comes in contact with the lower Cretaceous, the relation is one of intrusion while the Chico rests upon it undisturbed. The lower Cretaceous was intruded by the peridotite, upturned and eroded before the deposition of the Chico.

TERTIARY PERIOD.

Strata of Middle Tertiary age are widely distributed over this region and probably once covered nearly the whole of it. The Eocene on the contrary is entirely absent although extensively developed to the southeast in Santa Barbara and Ventura counties. It seems probable that during early Tertiary time this portion of the Coast Ranges was above water for if the Eocene ever had existed here it would be reasonable to expect some remnant of it would be met with. The Lower, Middle, and Upper Neocene are all represented.

NEOCENE.

Monterey series (*Lower Neocene*).—With the beginning of the Neocene a subsidance commenced and continued through, or nearly through the Miocene. Finally, almost the whole Coast Range region was submerged and a thickness of rocks in many places of more than 7000 feet was deposited. The most characteristic feature of the series is the bituminous shales. They form its upper portion and reach a thickness of 5000 feet. Below them are limestones, clays, volcanic ash, sandstones and conglomerates. Erosion has removed a large part of these rocks, but the similarity in succession of the characteristic horizons at various points in the area surveyed points to the fact of their former continuity.

The sandstones and conglomerates at the bottom of the series are most prominently developed in the region lying east of the Rinconada Valley, between it and the main granite range.

The thickness of these beds is remarkable, being 6000 to 8000 feet. They occupy the same position with reference to the bituminous shales as similar beds on the upper San Antonio River.

The volcanic ash forms a fairly constant horizon over nearly the whole of the region mapped. Several different centers of volcanic action seem to have existed in this region shortly after the beginning of the Miocene. In the mountains south of San Luis Obispo the ash has a thickness of fully 800 feet, while beginning near the Lion rock at the western end of the San Luis range this bed of volcanic ash extends easterly along the southern slope for a distance of over thirty miles. Near the centers of eruption the fragments are coarse, but farther away the deposit consists of frothy pumice, and in places occurring in beds of glass as fine as dust. On Old creek a small flow of banded rhyolite is associated with the fragmental material. It seems probable from the large amount of ash and small amount of massive lava that the eruptions were of an explosive nature and took place at or beneath the surface of the sea. This is the same eruption as that indicated at Point Sal.[1]

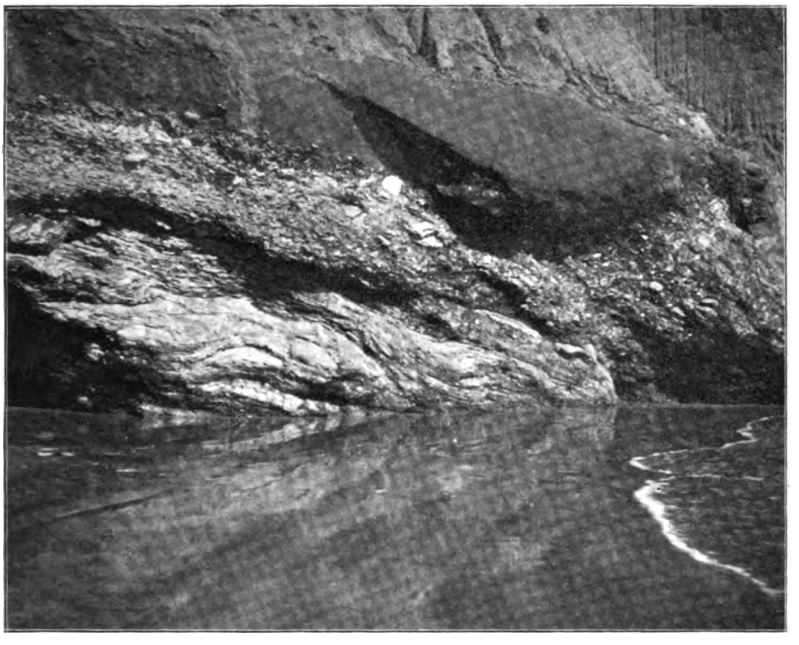
The bituminous shales and flints form the uppermost member of the Monterey series. They constitute the main portion of the San Luis range and that portion of the Santa Lucia range lying east of Cuesta Pass. They also underlie the younger formations in the upper Salinas Valley. This formation measured in both ranges appears to reach the enormous thickness of 5000 feet. It consists almost exclusively of a thin banded silicious shale which over extensive areas has been changed to a flint. Much remains to be done in a detailed study of these shales, although it has been quite certainly proved that they are largely of organic origin.[2] The shales are generally more or less impregnated with bituminous matter, and it appears to be reasonably certain that they constitute the main source of the oil and asphaltum which is so widely distributed through the Coast Ranges. Springs of thick oil and sulphurous water issue from

[1] Bull. Dept. of Geol., University of California, Vol. II, p. 16.

[2] Bull. Dept. of Geol., University of California, Vol. II, p. 13.

them, and when covered by porous beds vast deposits of bitumen have been formed.

San Pablo formation (*Middle Neocene*).—Overlying the Monterey series unconformably is a series of soft sandstones, diato-



Nonconformity between the San Pablo formation and the Monterey series. Ocean cliffs near Pismo.

maceous beds, and some flinty shales. It forms the eastern extension of the San Luis range between San Luis Obispo and the ocean, as well as a considerable area in the upper Salinas Valley. In the latter region it is filled with fossils which indicate the Middle Neocene, but to be more exact, whether the uppermost Miocene or the lowest Pliocene is as yet undetermined. Dr. Merriam has in a recent publication[1] described a series of strata on the southern shore of San Pablo Bay containing a similar fauna which he believes represents a distinct and

[1] Bull. Dept. of Geol., University of California, Vol. II, No. 4.

hitherto unrecognized palæontologic group. These strata it appears overlie those of the Contra Costa county Miocene with indications of a nonconformity, but the fossils collected from them by earlier palæontologists have in some cases been referred to the Miocene, in others to the Pliocene. To this series of rocks Dr. Merriam has given the name San Pablo formation. As the group of rocks in the southern Coast Ranges is undoubtedly the equivalent of those on San Pablo Bay, the latter name will be extended to it. In the San Luis Obispo region the nonconformity of this series of rocks with the Monterey series is distinctly shown in many places. Good examples appear along the coast north of Pismo as well as in the vicinity of Santa Margarita in the upper Salinas Valley. The basal conglomerates of the San Pablo formation, often but little disturbed, lap over on the more highly tilted and disturbed shales and contain many fragments of the latter often filled with mollusk borings. A great interval of time must have separated the deposition of the San Pablo formation from that of the bituminous shales, for the former formation extends over the shales in places and rests directly on the Golden Gate series. This time must have been sufficient for the erosion of at least 5000 feet of the Monterey series. During this time also the chief chemical change was wrought in the bituminous shales, for pebbles of the flinty altered shales occur at the base of the San Pablo formation in exactly the same condition as the shales on which this formation rests.

The discovery by Dr. Merriam of the marked palæontologic differentiation of the fauna of this group of rocks is an important addition to our knowledge of the younger formations of the Coast Ranges. That it is not a local condition is shown by the results reached by the writer along different lines and wholly independently. The pronounced nonconformity so clearly apparent in the San Luis Obispo region is confirmatory of the palæontologic investigations and firmly establishes the validity of the new formation. Its fauna is certainly older than that of the Merced beds, and if it should prove to be the upper-

most Miocene the rocks of that age in California can no longer be looked upon as forming a unit but separated into two divisions by an extended period of elevation and erosion. This point established other and puzzling questions relating to the Miocene and Pliocene are in a fair way to be cleared up.

Paso Robles formation.—The later Neocene in this portion of the Coast Ranges consists of a very extensive series of beds having apparently a fresh-water origin. They fill the Salinas Valley as far up as Atascadero, lapping over unconformably upon the upturned and sharply folded San Pablo formation. They are characteristically exposed about the town of Paso Robles, hence the designation. From Paso Robles the beds extend westward toward the Santa Lucia Mountains, and for many miles north and east of that place, filling the valley of the Estrella and its tributaries, and may reach into the Great Valley. The formation consists of conglomerates, sandy and marly clays, as a general thing, but slightly consolidated. The great extent of this formation in the drainage area of the upper Salinas River, its peculiar character and total absence of marine organisms, or organisms of any kind as far as observed, make it appear probable that it is of fresh-water origin, and for these reasons, though it is possibly contemporanous with the marine formation known as the Merced beds, it should be given a distinct name. The strata are generally almost horizontal, but along the Salinas River in particular they are tilted and faulted. Beds of the same character overlie the San Pablo formation in the vicinity of Arroyo Grande.

Fresh-water beds of Pliocene age are widely distributed through the Coast Ranges.[1] Those in the valleys of the upper San Benito and Salinas have been referred to by Lawson as Pliocene delta deposits,[2] and considered the equivalent of the Merced beds. While the latter view is probably correct, there is no reason to consider them delta deposits; on the contrary, they

[1] Monograph No. XIII, U. S. G. S., p. 238; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 152; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 363.

[2] Bull. Dept. of Geol., Univ. Cal., Vol. I, p. 153.

have decidedly the character of fresh-water lake beds, and there is no reason to believe that they were ever connected with the Merced beds.

PLEISTOCENE.

Under this designation are included the terrace formations, blown sand, stream gravels, and alluvial bottoms. These were not all formed at once, but represent a complicated history. The terrace formations belong to the oldest division. The most extensive area included under this head embraces a great stretch of sandy mesas and hills between the mouth of the Arroyo-Grande Creek and the Santa Maria River.

The coast, almost everywhere more or less distinctly terraced, forms an elevation of about ten feet above mean tide up to 750 feet. In addition terrace-like effects were noted upon the southern slope of the Santa Lucia range at elevations of 1000, 1400, and 1700 feet, aneroid measurements. In many places along the upper Salinas there are beautiful examples of river terraces cut upon the Paso Robles formation.

IGNEOUS ROCKS.

The igneous rocks of the San Luis Obispo region form one of the most interesting features of that field. Intrusives and surface flows are numerous, especially the former. They are so abundant in the Golden Gate series as in many places to form fully one-third of the surface exposures. The extensive sheets of diabase and peridotite appeared during the Cretaceous, and a great variety, though of much lesser extent, during the Miocene. The age of the andesite and dacite granophyre forming the buttes reaching from San Luis Obispo to Morro Bay cannot be determined with certainty. It certainly antedates the peridotites which appeared at the close of the Knoxville and may be of pre-Cretaceous age.

The igneous rocks, all taken together, show a great range in chemical and mineralogical composition, with examples of rare and interesting types. They have not yet been thoroughly

studied, and no detailed description will be attempted in the present paper.

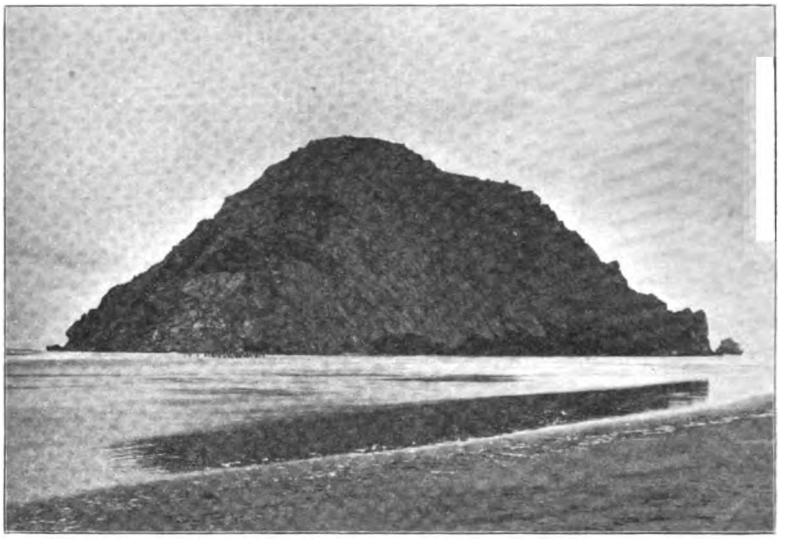
In the following outline the main types of igneous rocks occurring in this field will be given and arranged in groups according to age:

Granite,	Earlier than the Jurassic.
Basalt, intrusives and surface flows, Peridotite, Diabase,	Earlier than the Cretaceous. Intrusive in Golden Gate series.
Dacite granophyre, Andesite granophyre,	Earlier than the Middle Cretaceous. Possibly pre-Cretaceous. Intrusive in Golden Gate series.
Diabase,	Earlier than the Chico. Intrusive in Knoxville beds.
Peridotite serpentine and related feldspathic rocks, including diabase, gabbro, and pyroxenite,	Earlier than the Chico. Intrusive in the Knoxville and preceding diabase.
Rhyolite, Augite teschenite, and olivine diabase, Quartz basalt, Basalt,	All probably earlier than San Pablo formation. Intrusive in Monterey series.

The granite covers a large extent of country east of the upper Salinas River. It is remarkably uniform, consisting of quartz, biotite, orthoclase, plagioclase, and titantite. Large orthoclase phenocrysts give a porphyritic aspect in places. Numerous dikes of a finer-grained granite intersect it. Nothing is known concerning the age of the granite, save that it forms the southeastern continuation of the crystalline axis of western Monterey county, on which the Golden Gate series rests with a basal conglomerate. It is certainly much older than the Jurassic.

The dikes of basic pre-Cretaceous intrusives in the Golden Gate series are almost innumerable, and, as they are generally much altered, weather away readily and are difficult to map accurately. Owing to the disturbances which the series has undergone, it is also almost impossible to distinguish in all cases the surface basalts from the dikes with similar appearance. The

greater number of the dikes are fine grained and amygdaloidal on the edges. Dikes of diabase are also numerous. The rock having the most limited distribution is the peridotite. This is not as much decomposed as might be expected, considering its



Morro Rock (dacite granophyre) on the coast at mouth of Morro Bay.

age, and consists of olivine, a rhombic pyroxene, and sometimes augite and a little feldspar. The dikes follow the strike of the rocks, and are more abundant in the jasper horizons. Contemporaneous flows were not recognized with certainty, and it is the writer's opinion that they are more rare upon the San Francisco peninsula than Lawson has supposed. They are not all of the same age. The surface flows did not take place until after the Golden Gate series had been upturned and planed off. This is shown in the hills east of Los Osos Valley.

The dacite and andesite granophyres are strikingly interesting rocks. The occur as roundish or lenticular plugs forming the large buttes, besides many small ones, between San Luis Obispo and Morro Bay. The dacite variety is confined to sev-

eral of the northern ones, the andesite to those nearer San Luis Obispo. The important constituents of the former are quartz, biotite, and an acid plagioclase feldspar; of the latter labradorite, biotite, and enstatite, as porphyritic constituents in a granular base. Morro Rock is the most striking topographic feature on the coast of California.

The diabase intrusive in the Knoxville beds has a character different from any other rocks in the region under investigation. It is grayish in color, fine grained, and amygdaloidal upon the edges. It has come up in great dikes or sheets on either side of the main Knoxville area, throwing the latter into a synclinal trough. It extends northwest from Cuesta Pass for many miles, and is quite uniform save for local gabbroitic variations.

The peridotites and related feldspathic rocks of the Coast Ranges are well known. The great body of this rock in the San Luis Obispo region has been changed to serpentine. It consisted originally of olivine and augite. Local variations rich in feldspar occur along the Santa Lucia range forming diabase and gabbro. The feldspathic facies is quite extensively developed not only upon the borders of the great serpentine area north of San Luis Opispo, but also in many places as apparently independent intrusions. From their similarity in character it is easy to see, however, that all these rocks are genetically related. The serpentine has the usual sheet or lense-like character conformable to the dip and strike of the inclosing rocks, which usually stand very steeply.

The igneous rocks of Tertiary age have a great range in chemical and mineralogical composition. The succession of these rocks was only partly determined. The oldest is the rhyolite of which there are two varieties. One contains free quarts and occurs as a very limited surface flow, being mostly represented by tuffs. The other has the form of long, narrow sheets intruded near the base of the Miocene, and contains no free quartz, but an abundance of plagioclase phenocrysts. The ash which is so widespread at this horizon appears to be connected with rhyolite eruptions, but these particular sheets are

probably of later date, as they are clearly not surface flows. The ash reaches in places a thickness of many hundreds of feet, and in the hills south of San Luis Obispo passes downward into an agglomerate of bowlders of perlitic glass, many of them of large size.

The surface flow of rhyolite on Old Creek is very interesting. It is only a few feet in thickness and imbedded in a great mass of tuffs of the same character. The sheet terminates at one edge in flattened nodular masses from one-half inch to eight inches in diameter. Some of these are entirely free, others more or less connected in the plane of flow. Superficially many of these nodules appear like concretions or large spherulites, but their internal character is entirely different. The flowage lines pass through them regularly without regard to the shape of the surface, and the interior appears to have shrunken away from the center, from which radiating cracks either empty or filled with chalcedony spread toward the outside. These cracks break across the banding with but little disturbance of the latter. They do not appear to be real spherulites and the field relations suggest that their peculiar character may be due to sudden cooling under water.

The augite teschenite and olivine diabase form two generally distinct variations of one magma. The former rock contains varying proportions of analcite and its alteration products, augite and a basic feldspar. The typical examples are rather light colored rocks, but with the appearance of olivine and a decrease of feldspar and analcite the rock becomes very dark and basic looking. Some of the olivine diabase contains so little feldspar that it might with almost as much propriety be termed a peridotite. These rocks are among the most interesting of any yet discovered in the Coast Ranges, and as far as is yet known the augite-teschenite is confined to Santa Barbara and San Luis Obispo counties. It has been described in former papers.[1] Not only is it petrographically interesting, but remarkable for its structural relations to the Miocene in which it is intruded.

[1] Bull. Depart. of Geol., Univ. of Cal., Vol. I, p. 273; *ibid.*, Vol. II, p. 19.

The quartz basalt occurs in the form of dikes intruded at the base of the Miocene east of Edna. The larger one is nearly continuous, following the strike of the rocks for two and one-half miles. The rock is dark and fine grained with a few scattering phenocrysts of labradorite feldspar. The most important phenocrysts are quartz scattered in a fairly uniform manner through the rock. The quartz grains show the effects of corrosion and are surrounded by augite microlites. The analysis shows that the rock has a rather low percentage of lime, but there can be no doubt that it belongs among the basalts.

Other Tertiary basalts occur on a small scale at several different points, but they have no striking features and will not be described here. It is impossible to determine the relative ages of these basic igneous rocks, although it would seem that with the exception of the rhyolite they followed the disturbances which folded the Miocene.

STRUCTURAL GEOLOGY.

Nearly all the structural features have a linear arrangement along northwest and southeast lines. The mountains are structurally synclines elevated by comparatively recent movements, the most important being faulting. This region may be divided in a general way into five crustal blocks, as follows, beginning on the north: the granite and associated rocks north of the Salinas Valley, the depression occupied by the Salinas Valley, the Santa Lucia range, the western foothills of this range and the broad valleys at its southern base, and last, the San Luis range. Each of these blocks has behaved as a unit since Miocene, or in several cases very much earlier times. All the faulting now recognizable dates from later Neocene time. The Santa Lucia range constitutes a remarkable fault block. It has been elevated, not by a single fault on each side, but in most places by several forming step faults. A fault line follows the lowest portion of the Salinas Valley, and other lines of folding and faulting are to be seen along the northern slope of the Buchon range.

One of the most striking structural features is the occurrence in the Monterey shales of the Buchon range of great bodies of bituminized sand forced into its present position during the folding which terminated the deposition of the San Pablo formation. There are two of these sand pockets or bosses north of Sycamore Springs. They occur near the ends of subordinate anticlinal folds. The largest body of sand is fully 500 feet across, elongated somewhat in the direction of the strike of the shales and with narrow dikes radiating from it. The sand has probably been forced in from beneath from the adjoining San Pablo formation, as the nose-shaped terminations of the anticlines in which the sand appears have been forced slightly over that formation.

The structural relations of some of the igneous rocks are quite remarkable. Especially is this true of those which have appeared in the Monterey series. Bodies of the teschenite and olivine diabase magmas have come up underneath this series but have rarely if ever broken completely through it. Having penetrated as far upward as the limestones or bituminous shales they have spread out between the strata in sheet form. Two remarkable cases occur north of San Luis Obispo between it and the railroad water tanks. Here are two hills, one a half mile in diameter, the other nearly a mile, rising quite abruptly from the lower rolling country and capped by a thin layer of Monterey limestone and shale. Each hill has an amphitheater-like center, the strata dipping inward from all sides but one, and from this a depression has been eroded. The peculiar topography and saucer-like structure is due in each case to a sheet of teschenite which outcrops around the steep outer slope metamorphosing the overlying rocks. From a general study of the region it seems likely that the Monterey series had already undergone disturbance and folding when these igneous rocks appeared.

One of the crests of the Santa Lucia range about 20 miles north of San Luis Obispo has on its summit a long narrow remnant of Monterey shales folded in synclinal form. For some

miles the center of this syncline has been broken through by bodies of olivine diabase. They appear as dikes or bunches which as exposed in places have lifted up and inclosed large masses of the shale.

On Old Creek there are very large sheets of the diabase, from the upper surface of which the Monterey shales have been nearly removed, as they occur only in patches here and there. These igneous masses in many respects resemble laccolites, only that instead of having arched the strata in dome form they appear as saucer-shaped sheets issuing from lines of fracture along centers of synclines.

GEOLOGICAL HISTORY.

The geological history of this region is exceedingly complicated, and in the short review following only the merest outline can be given. The earliest event of which we have any record in the Coast Ranges was the invasion of the crust by great masses of molten granite, metamorphosing the existing sediments to marbles and schists. The date of this convulsion is unknown save that it must have long antedated the Jurassic. With the beginning of the deposition of the Golden Gate series the great area of crystalline rocks which had for so long a time formed a land mass in the region of the present Coast Ranges began to subside and continued to do so with oscillatory movements until its close. Although this formation is so widespread it is essentially a near shore or shallow water formation as it consists so largely of sandstone. The conditions at times changed and the sea bottom instead of being subjected to sedimentation from the land was covered with the siliceous skeletons of radiolaria which it is believed form the main portion of the lenticular jasper beds.

With the upheaval of the series, and in some cases possibly earlier, appeared dikes and sheets of basic igneous rocks which everywhere so abundantly characterize it. After erosion had planed off the surface flows of basalt took place.

The period of the intrusion of the more acid plugs forming the line of buttes between San Luis Obispo and Morro Bay is

not exactly known. It may have taken place before the deposition of the Knoxville beds.

With the beginning of the Cretaceous the Coast Range region sank and the thin bedded sandstones and dark shales of Knoxville age were formed. They lie unconformably upon the upturned strata of the Golden Gate series and their basic intrusives.

At the close of the Knoxville a disturbance not heretofore recognized in the Coast Ranges took place and the great masses of diabase were formed which threw the beds of that age along the Santa Lucia into a synclinal form. Before the beginning of the Chico another important event took place. This was the welling up of vast bodies of peridotite, now altered to serpentine, which appear everywhere in the Coast Ranges in rocks older than the Chico. Dikes of serpentine penetrate the diabase just referred to and are therefore younger. It is then clear that the conglomerate at the base of the Chico and the nonconformity of this formation upon the Knoxville is due to a widespread disturbance resulting in an elevation of the region above the sea during a portion of the Middle Cretaceous.

The Eocene is absent from this portion of the Coast Ranges and it is legitimate to infer that the region was above water during the whole period.

Before the inauguration of the Neocene sinking commenced, and we find rocks of this period everywhere underlaid by a conglomerate formed as the sea encroached upon the land. Shortly after the beginning of the deposition of the Monterey series violent volcanic disturbances are recorded as having taken place. Local flows of rhyolite occurred and ash of that composition in the form of glass was thrown out in vast quantities and distributed over the sea for many miles. Following this the bituminous shales and limestones were formed. They consist almost wholly of organic material, the more or less blended and broken skeletons of foraminifera, diatoms, and radiolaria. A very extended period of time must have been required for the deposition of 5000 feet of these sediments which are believed to accumulate

slowly. Peculiar conditions must have existed, the sea being practically free from detrital material though the area of deposition could not have been far removed from the land.

The latest igneous action in this region probably followed the initial folding of the Monterey series preceding the deposition of the San Pablo formation, when the basalt, teschenite, and olivine diabase appeared.

After a period of elevation and prolonged erosion during which the great thickness of Monterey series was totally removed from some areas, and the shales of that period had undergone a chemical change, a subsidance began and the sandy strata of the San Pablo formation were laid down. The present configuration did not exist and this formation probably spread across the Santa Lucia range.

The discovery of the nonconformity of the San Pablo formation upon the bituminous shales (Monterey series) necessitates the addition of a correction to the diagram recently published illustrating the oscillations of the Coast Ranges.[1] Two oscillations should appear where the one is represented as separating the Miocene and Pliocene, with the understanding that the dividing line between these two periods is not at present settled.

After a deposition of at least 3000 feet of sediments, elevation and folding were experienced, terminating the San Pablo period; and the outlines of the present mountains were originated.

Marine formations of late Neocene age have not with certainty been recognized in this region. The Paso Robles formation indicates the existence of fresh-water lakes of large extent. With the close of the Neocene an upward movement was inaugurated and continued, it is believed, until the region was much higher than at present.

Following this early Pleistocene elevation a reversal took place and sinking went on until the coast was submerged to the depth of the highest terraces. With the gradual recovery from this depression the lower terraces were formed and again a point

[1] American Geologist, Vol. XX, p. 225.

was reached somewhat above the present. How much this was is not known for the mouths of all streams have been flooded by the ocean. The last movement has been one of subsidance as shown not only by the flooded stream mouths but by Morro Bay, a sheet of water whose origin can only be accounted for by the theory of a depression.

It is hoped that the foregoing discussion will convey some conception of the interesting and complicated problems encountered in the geology of the Coast Ranges.

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